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THE ASSOCIATION was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of over 700 men. Its membership is divided into two principal classes, viz.: MEMBERS and ASSOCIATES. Members are divided into two classes, viz.: RESIDENT and NON-RESIDENT, — the former comprising those residing within the limits of New England, while the latter class includes those residing elsewhere. The INITIATION fee for the former class is FIVE dollars; for the latter, THREE dollars. The annual dues for both classes of Active membership are THREE dollars. Associate membership is open to firms or agents of firms engaged in dealing in water works supplies. The initiation fee for Associate membership is TEN dollars, and the annual dues FIFTEEN dollars. This Association has six regular meetings each year, all of which, except the annual convention in September, are held at Boston.

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Page 256, Table 1. eighth column, in heading read (CO_2) instead of "(CO_3)."

NEW ENGLAND WATER WORKS ASSOCIATION.

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This Association, as a body, is not responsible for the statements or opinions of any of its members.

NEW YORK CITY WATER SUPPLY.

BY WILLIAM W. BRUSH, ENGINEER OF DISTRIBUTION, BOARD OF WATER SUPPLY, NEW YORK.

[*Read September 9, 1909.*]

The present city of New York is divided into the boroughs of Manhattan, Brooklyn, The Bronx, Queens, and Richmond, these boroughs, with the exception of Manhattan, being made up of many communities which, prior to consolidation, were incorporated as villages, towns, and cities. About twenty-five separate systems of water supply served the territory covered by Greater New York, and practically all these systems are still in use. To give, in this paper, an intelligent idea of the New York water supply, only the large systems can be described in any detail, and borough lines will be the basis of division. As one supply is used for Manhattan and a portion of The Bronx, these boroughs will be taken together, and Brooklyn, Queens, and Richmond treated separately.

The new supply from the Catskills is the first system that has been designed to supply water to all the boroughs comprising the greater city and will practically cross-connect all the existing systems.

BOROUGHS OF MANHATTAN AND THE BRONX.

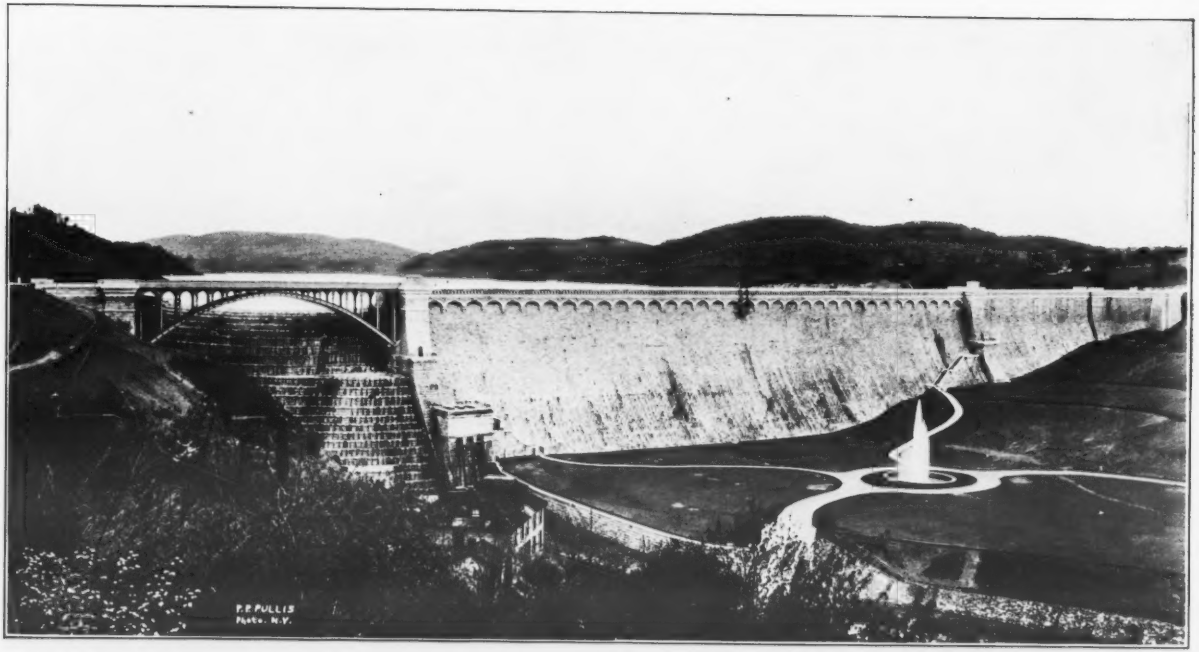
During the latter part of the eighteenth and the early part of the nineteenth centuries, several attempts were made to furnish a water supply from wells on Manhattan Island, but the quantity and quality of the water were so unsatisfactory that the introduction of a water supply system for what is now the Borough of

Manhattan may be properly said to date from 1842, when water from the Croton River was first utilized, the population at that time being about three hundred and fifty thousand. This supply was supplemented by an emergency supply from the Bronx and Byram rivers, the Bronx supply being introduced in 1884, and the Byram in about 1897. The available supply from the Croton River was greatly increased by the construction of the new Croton aqueduct, which was put into service in 1890, and by the extension of the Croton Reservoir system, which is still in progress.

The Croton supply is taken from the Croton River, which lies about 30 miles to the north of New York City and discharges into the east side of the Hudson River. The watershed is hilly, having a comparatively impervious soil, and is rather sparsely settled, except in the immediate vicinity of several thriving villages located within the boundaries of the drainage area. The total tributary area is 360 square miles, of which about 19.3 square miles are water surface. The main dam, known as the New Croton Dam, is constructed across the valley about 6 miles from the point where the river joins the Hudson. This dam is of rubble masonry, faced with ashlar, having its foundation on rock, the lowest point of the foundation being 123 feet below the river bed, which at this point is 173 feet below the top of the dam. The crest of the spillway is at an elevation* of 196 for 250 feet, and at an elevation of 200 for the remaining 750 feet. The water level can be raised by flashboards to an elevation of 202, the top of the dam being at elevation of 210. The dam, including a spillway of 1 000 feet, is 2 168 feet long and contains about 850 000 cubic yards of masonry. Construction was commenced in 1892 and the works sufficiently completed to be used in 1905. The total cost, including land, was about $15 000 000. The reservoir formed by this dam is 20 miles long and has a storage, at the spillway level, of nearly 38 000 m. g.,† of which about 31 000 m. g. are above the invert of the aqueduct, and, therefore, ordinarily available. The original, or Old Croton Dam, which is located about 3 miles above the new dam, is flooded by this reservoir to a depth of 34 feet.

* All elevations given refer to the datum used for the respective systems. The datum for the Board of Water Supply is mean sea level at Sandy Hook, which is 0.5 feet above the Croton datum and 1.7 feet below the Brooklyn datum.

† m. g. stands for "million gallons" and m. g. d. for "million gallons daily."



THE NEW CROTON DAM AND RESERVOIR.

PLATE I.

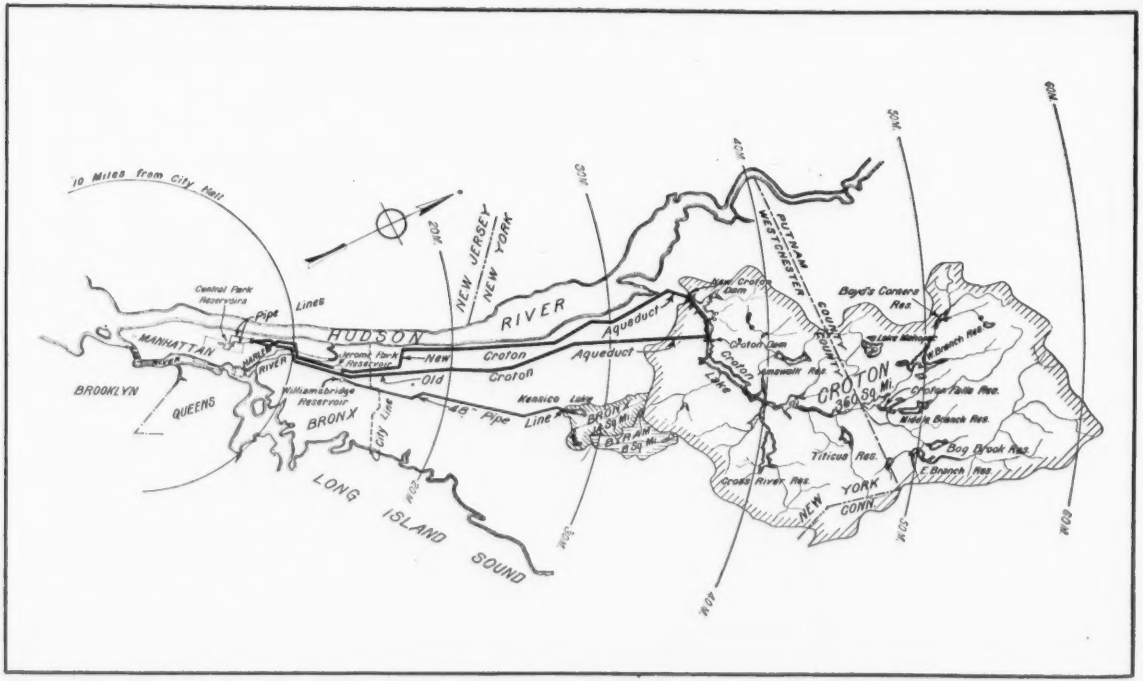


FIG. 1. CROTON, BRONX AND BYRAM WATERSHEDS, SHOWING RESERVOIR, AQUEDUCT, AND PIPE LINES.

TABLE No. 1.

RESERVOIRS ON CROTON, BRONX AND BYRAM WATERSHEDS.

Name.	Year when First Utilized.	Elevation of Spillway. Feet.	Water Surface. Sq. M.	Storage, including Flash-boards. M. G.	Tributary Watershed. Sq. M.
		Croton.			
Old Croton	1842	166	0.760	2 000	339
Boyd's Corners	1873	600	0.436	2 730	21
Middle Branch	1878	380	0.672	4 160	21
East Branch	1891	417	0.898	5 240	73
Bog Brook	1891	417	0.640	4 400	4
Titicus	1893	325	1.103	7 620	23
West Branch	1895	503	1.560	10 730	41
Amawalk	1897	400	0.940	7 090	71
New Croton	1905	200	5.574	26 110†	360
Muscoot	1905	200		5 700	...
Cross River	1908	330	1.310	10 920	29
Croton Falls	Under construction	310	1.910	15 780	100
Fourteen natural ponds	1870	...	.....	2 060	...
Total			19.32*	104 540	
		Bronx and Byram.			
Lake Kensico	1884	250	0.39	1 797	22
Byram diverting reservoir	1897	...	0.12	180	8
Byram Lake	1897	...	0.25	664	...
Rye Ponds	1884	301	0.44	1 440	...
Wampus Lake	....	...	0.08	60	...
Total				4 141	

An auxiliary dam, called the Muscoot dam, has been built to hold the water in the upper end of the New Croton Reservoir when the water in the main portion of the reservoir is drawn down, to avoid exposing large areas where the water is shallow when the reservoir is full. Eight auxiliary reservoirs have been formed by masonry dams and earthern dikes, constructed on the various tributary streams and branches. The stored water in these reservoirs is

* Includes all ponds on watershed. There are 28 ponds in addition to those noted above, or a total of 52.

† There are 6 123 m. g. in the Croton Reservoir below the aqueduct level, and, therefore, not available without pumping. This storage is not included in the contents as given.

discharged, as required, into the natural water courses and allowed to flow to the main reservoir. Fourteen lakes and ponds are also utilized to some extent for storage.

The Croton Falls Reservoir, which is now under construction, will give an additional storage reservoir on what is known as the west branch of the Croton River, and a diverting dam and channel will convey water from the east branch into this reservoir. Upon the completion of this reservoir, the total available storage, including that obtained by flashboards, will be about 105 000 m. g., which is equivalent to 290 m. g. per square mile of watershed.

The yearly rainfall on the Croton watershed averages about 48 inches, and the estimated safe minimum yield, based on the stream flow as measured since 1868, and assuming the completion of the Croton Falls reservoir, is 336 m. g. d., which is equivalent to 930 000 gallons per square mile of watershed. With the present large water surface the evaporation exceeds at times the minimum monthly flow.

There are two aqueducts available to convey the water to the city, the intake being at a large gatehouse located just below the Old Croton dam. These aqueducts are known as the "Old" and "New" Croton, respectively. The Old Croton Aqueduct has its invert at elevation of 153, having, in general, interior dimensions of 7½ feet wide by 8 feet high, giving a cross-section of about 53 square feet. Its slope is 1.1 feet per mile, with a capacity of about 80 m. g. d. The aqueduct is 34 miles long, of which 4 miles are in earth or rock tunnel, the remainder being cut-and-cover section. The New Croton Aqueduct has its invert at elevation of 140, is usually of horseshoe shape, 13.6 feet wide and 13.5 feet high, with an area of 154 square feet. The slope is .7 foot per mile and it has a capacity of 300 m. g. d. The aqueduct is almost wholly in rock tunnel, it is brick lined and is 31 miles long, of which only a little over 1 mile is cut-and-cover. The total aqueduct capacity for the Old and New Croton is slightly less than 400 m. g. d.

The aqueducts are now connected to a large receiving and equalizing reservoir, known as the Jerome Park Reservoir, which is located at the southerly end of Van Cortlandt Park, about 3 miles south of the city line, and to the west of Jerome Avenue. This reservoir is divided into two basins, the westerly one having been

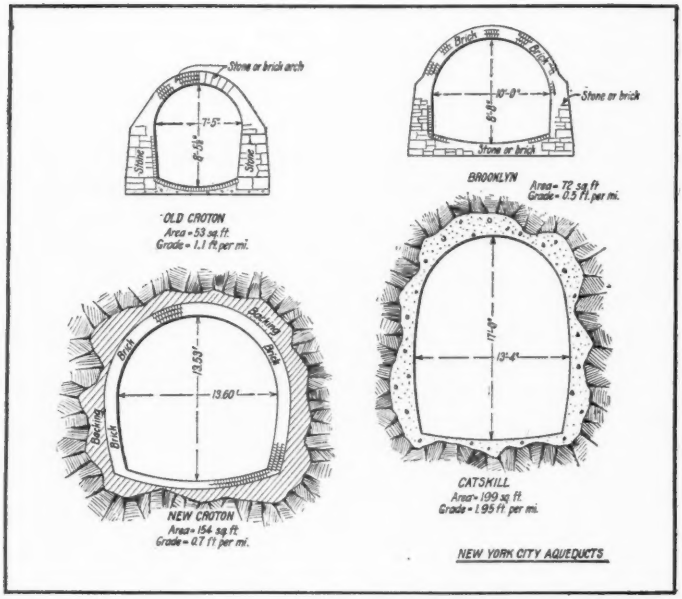


FIG. 2. TYPICAL SECTIONS OF CROTON AQUEDUCTS.

With the maximum section of Brooklyn aqueduct and grade tunnel section of the Catskill aqueduct. The Catskill and New Croton sections are for grade tunnel.

sufficiently completed to put into use in 1905. After the greater part of the excavation for the easterly basin was completed, it was decided to suspend construction, in anticipation that this basin would be used in connection with a future filtration plant for the Croton supply. The reservoir has a flow line at elevation of 134, the bottom elevation being about 107. The west basin has an area of 94 acres and a capacity of about 770 m. g., while the east basin has 50 per cent. greater area.

The Old Croton aqueduct, which previously passed through the site of the west basin, has been diverted within the limits of the basin to a new aqueduct built through the dividing wall, and continues in cut-and-cover to the Harlem River, where it crosses in one 7-foot and two 3-foot pipes over an imposing masonry arch bridge known as High Bridge. The cut-and-cover section is continued to a gatehouse at Amsterdam Avenue and 135th Street, constructed at the time when the New Croton Aqueduct was built. The New Croton Aqueduct drops rapidly just north of the Jerome Park Reservoir into a circular brick-lined tunnel 12.25 feet in diameter, with invert 7.6 feet above tide water. A branch aqueduct connects the main aqueduct with the reservoir, and the water from the reservoir can flow into the tunnel through a downtake shaft connected to the central gatehouse. At the Harlem River the tunnel drops through a shaft to an elevation of about 300, the diameter reducing to 10 feet. On the west side of the Harlem River the tunnel is brought up a vertical shaft to elevation of 13.5, provision being made to pump out the tunnel from this shaft, and continues with an upward gradient to elevation of 21.6 at the uptake shaft at the 135th Street gatehouse. The pressure on this tunnel varies from about 50 pounds per square inch for the land section to nearly 200 pounds per square inch, or about 450 feet, for the river section. The pressure tunnel section, which is 36 000 feet long, showed a leakage of 228 000 gallons per twenty-four hours when tested upon completion. From the gatehouse the water is carried mainly in 48-inch cast-iron mains, to the distribution system and to the distributing reservoirs in Central Park.

These distributing reservoirs consist of three basins, the two southerly basins being known as the Old Reservoir, constructed as

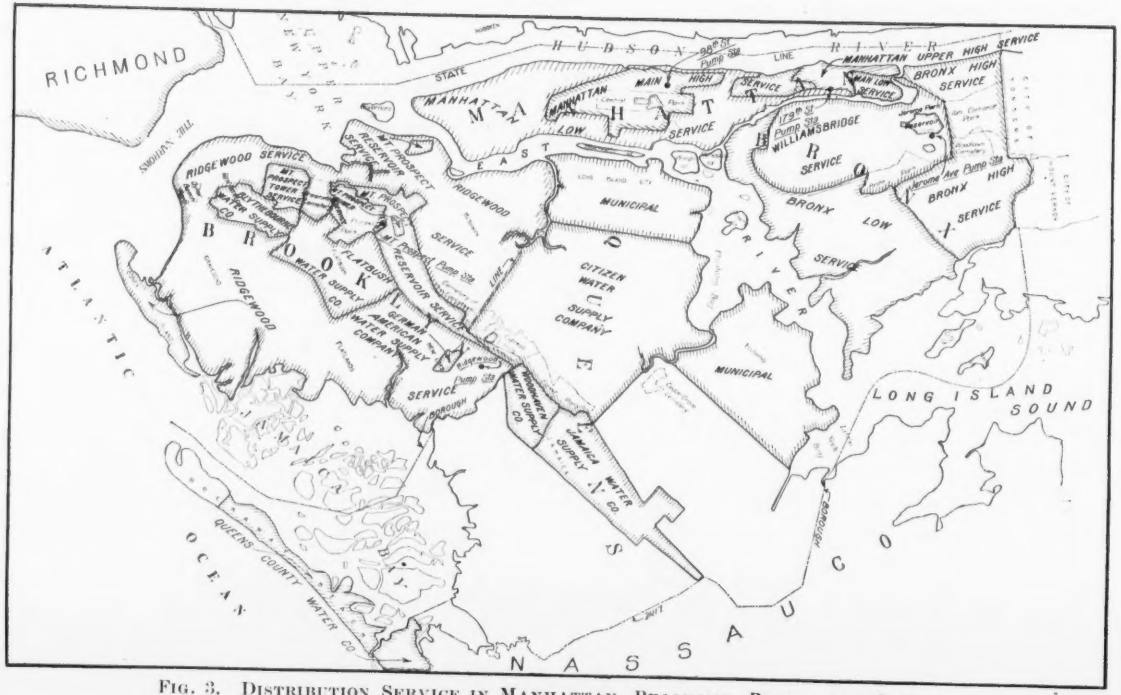


FIG. 3. DISTRIBUTION SERVICE IN MANHATTAN, BROOKLYN, BRONX, AND QUEENS.

TABLE No. 2.

DISTRIBUTION SERVICES. BOROUGHS OF MANHATTAN AND

Manhattan.

Designation.	Area Supplied.	Population Served.	Consumption. M. G. D.	Reservoirs and Standpipes.		
				Name.	Location.	Source of Supply
Low service.	Southerly and easterly sections lying mainly below elevation 40.	1 900 000	230	Old Central Park Reservoir.	Between 79th and 86th sts.	Croton River throu and New Croton
				New Central Park Reservoir.	Between 86th and 95th sts.	ducts.
Main high service.	Central and westerly sections above 34th St.	340 000	60	High Bridge Reservoir.	175th St. and Harlem River.	High Bridge and 17 Stations.
				179th St. Standpipe.	179th St. and Harlem River.	179th St. Station.
				98th St. Standpipe.	98th St. west of Columbus Ave.	98th St. Station.
Upper high service.	Northerly section.	30 000	7	High Bridge Standpipe.	175th St. and Harlem River.	179th St. Station.
				Bronx.		
Low service.	Easterly section and low ground in southerly section and near Harlem River.	170 000	10	Jerome Park Reservoir, West Basin.	Jerome Ave. between E. 194th St. and E. 210th St.	Old and New Croton ducts.
Williamsbridge service.	Central section.	120 000	16	Williamsbridge Reservoir.	E. 208th St. and Woodlawn Road.	Bronx and Bryam ri
Bronx high service.	Northerly and westerly sections.	50 000	10	Jerome Ave. Standpipe.	Jerome Ave. and Van Cortlandt Ave.	Jerome Ave. Station

				Pumping Stations.			
Supply.	Elevation of Nominal High Water. Feet.	Depth. Feet.	Capacity. M. G.	Name.	Location.	Source of Supply.	Pumpage. M. G. D.
through Old Croton aqueduct	118	20 & 30 36	211 1 000	Gravity supply.			
nd 179th St.	225	16	11	High Bridge.	Same as reservoirs and standpipes.	Old Croton Aqueduct.	2
ion.	225	134	.028	179th St.		New Croton Aqueduct.	40
n.	219	170	.036	98th St.		Both aqueducts.	18
ion.	324	243	.056	179th St.	Do.	Do.	7
Croton aqueduct	134	27	770		Gravity supply.		
am rivers.	193	37	140		Gravity supply.		
tation.	303	185	.039	Jerome Ave.	Same as standpipe.	Jerome Ave. Reservoir and Old Croton Aqueduct.	10

part of the original works, and the northerly basin as the New Reservoir, this basin being put in service in 1862. The normal flow-line is at elevation of 118, and the capacity of the three basins is about 1 200 m. g. A distributing reservoir, formerly located on 5th Avenue, between 40 and 42d streets, was removed in about 1901, and a public library building has been erected on this site.

About 75 per cent., or 240 m. g. d., of the Croton supply is distributed from the low level reservoirs, which gives a resulting hydraulic gradient in downtown Manhattan, during the day time, equivalent to elevation of about 70. As a large area of the Bronx and Manhattan boroughs lies above the level which can be supplied from the low level reservoirs, high services have been created by pumping the Croton water. The intermediate high service in Manhattan, which is known as the main high service, requires about 60 m. g. d., which is pumped at stations located at 98th Street, near Columbus Avenue, and 179th Street and the Harlem River, a small station at High Bridge being a reserve station. The 98th Street station pumps about 15 m. g. d. into a tower at the station, with an overflow at elevation of 219, while the 179th Street station pumps about 45 m. g. d. into its tower, with an overflow at 225. A small reservoir located at the westerly end of High Bridge is also used for this service. The upper high service supply of about 7 m. g. d. is pumped at the 179th Street station against the High Bridge standpipe pressure, this standpipe having an overflow at an elevation of about 324, and serves the high ground lying at the northerly end of Manhattan Island, this ground rising to a maximum elevation of 240.

In the borough of The Bronx the low ground is served by the Croton from the Old Aqueduct and Jerome Park Reservoir. The supply from the Bronx and Byram rivers is taken from Lake Kensico, formed by a dam across the Bronx River at Kensico, N. Y., and delivered by a single 48-inch pipe, 15.2 miles long, to the Williamsbridge Reservoir located to the east of the Jerome Park Reservoir. The watershed tributary to Lake Kensico is 22 square miles, and there are four upper lakes available for storage, having, with Lake Kensico, 4 141 m. g. capacity. The supply, which averages about 20 m. g. d., is used for the intermediate service in The Bronx, any surplus flowing into the Croton low service. The

Williamsbridge Reservoir contains 140 m. g., with the water level at elevation of 193.

The high ground, which rises to a maximum elevation of about 280, is supplied by the Bronx high service. The Jerome Avenue station, located just east of the Jerome Park Reservoir, pumps about 10 m. g. d. into a standpipe with an overflow of elevation 303. This supply comes from the Croton low level system.

The distribution system consists of 1 200 miles of mains, varying from 4 to 60 inches in diameter, on which have been set 18 500 gates and 18 400 hydrants. There are about 150 000 services, of which about one third are metered. The average daily consumption of the boroughs of Manhattan and The Bronx is about 330 m. g., and the population, 2 600 000, which gives a per capita use of 127 gallons daily.

The original Croton works cost $12 000 000, and with the additions since that time, including the Bronx and Byram works, have cost about $100 000 000.

In connection with the water supply system, a separate high pressure fire service has been installed to reduce the fire loss and conflagration hazard in the downtown section of the borough of Manhattan. This system at present covers an area of about 1 450 acres, being bounded, approximately, by the Hudson River, 23d Street, Broadway and the Bowery, and Chambers Street. Within this area 50 miles of mains from 12 to 24 inches in diameter have been laid, with 896 gates and 1 274 hydrants. There are about 5 miles of 8-inch pipe laid for hydrant connections and an 8-inch valve on each connection. The mains are supplied by two pumping stations, one located on the East River at Oliver Street opposite, approximately, the southeast corner of the protected district, and the other at Gansevoort Market on the Hudson River, in the northwesterly part of the district. Each station is connected to use either the salt water from the river or the fresh water from the Croton system, it being expected to use the salt water only as an emergency supply. Each station has five Allis-Chalmers 6-stage turbine pumps, driven by electric motor, each pump being capable of delivering 3 000 gallons per minute against a head of 300 pounds per square inch at the station. The ordinary fire engine can pump about 700 gallons per minute

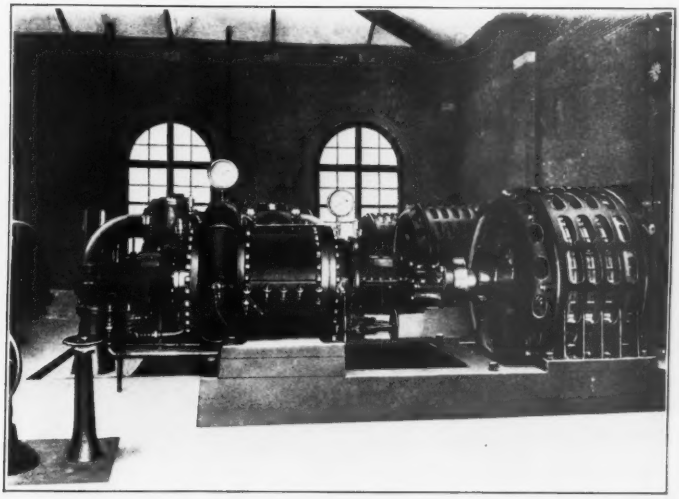


FIG. 1. A PUMPING UNIT. GANSEVOORT HIGH PRESSURE STATION.

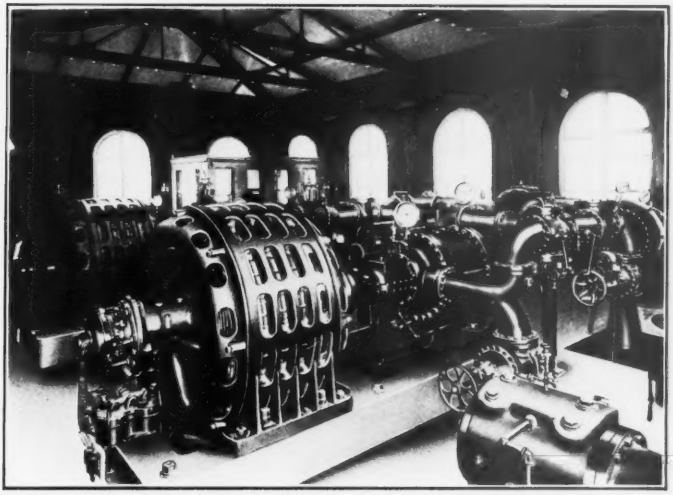


FIG. 2. INTERIOR OF GANSEVOORT HIGH PRESSURE STATION.

TEST OF HIGH PRESSURE FIRE SERVICE ON WEST STREET, NEAR GANSEVOORT STATION.

at a pressure of somewhat less than 200 pounds per square inch, and the combined capacity of the two high-pressure stations is equal, therefore, to more than 40 fire engines, each furnishing two good streams. Each hydrant is equipped with three 3-inch and one 4½-inch outlet, with independent valves, and, by siamesing, approximately 10 lines of hose can be run from each hydrant. The hydrants are of special design manufactured by the A. P. Smith Manufacturing Company. Extensions to this system are now under contract to cover a portion of the East Side bounded by James Street, Bowery, East Houston Street, and the East River, this district being considered a serious conflagration hazard, menacing to other and more valuable portions of the city. The high-pressure system has cost somewhat less than $4 000 000 for stations, land, mains, and appurtenances. The extensions now under way are estimated to cost about $1 500 000.

The construction of reservoirs and other developments in the Croton system is under the Aqueduct Commission, consisting of Mayor George B. McClellan; Comptroller Herman A. Metz, Commissioners J. F. Cowan, president; W. H. Ten Eyck, J. J. Ryan, and J. P. Windolph; Mr. Walter H. Sears being chief engineer. The maintenance and operation of the Croton system, together with all work on distribution, including the high pressure system, is under the Commissioner of Water Supply, Gas and Electricity, Mr. John H. O'Brien, Mr. I. M. de Varona being chief engineer.

BOROUGH OF BROOKLYN.

Brooklyn was dependent upon individual private and public wells and cisterns prior to the introduction of water from the Ridgewood system in 1859. At this time the population was about 250 000, the total area of what was then incorporated as the city of Brooklyn being less than one half of the territory at present included in the borough of Brooklyn. The original works extended about 12 miles to the east of what is now the borough line between Brooklyn and Queens, along the south shore of Long Island, and in 1890 an additional supply was obtained by extending the terminus about 10 miles to the east, thus including practically all the territory on the south side of the island to the west of the

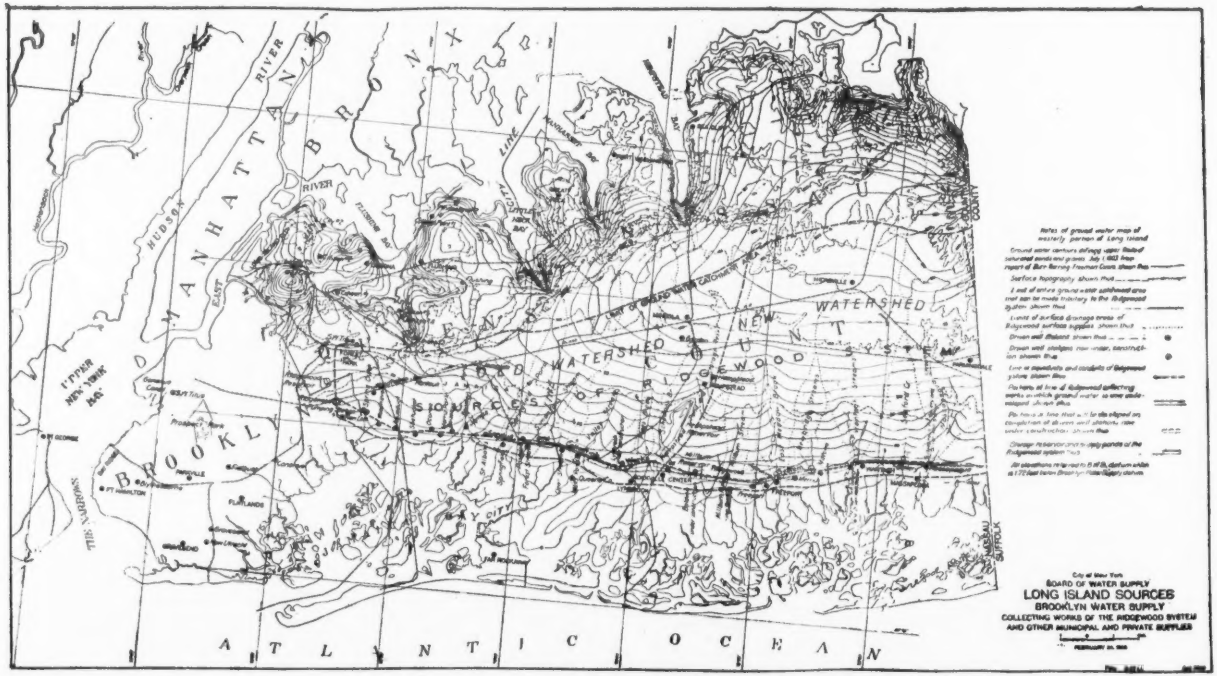


FIG. 4. SOURCES OF SUPPLY FOR BROOKLYN AND QUEENS.

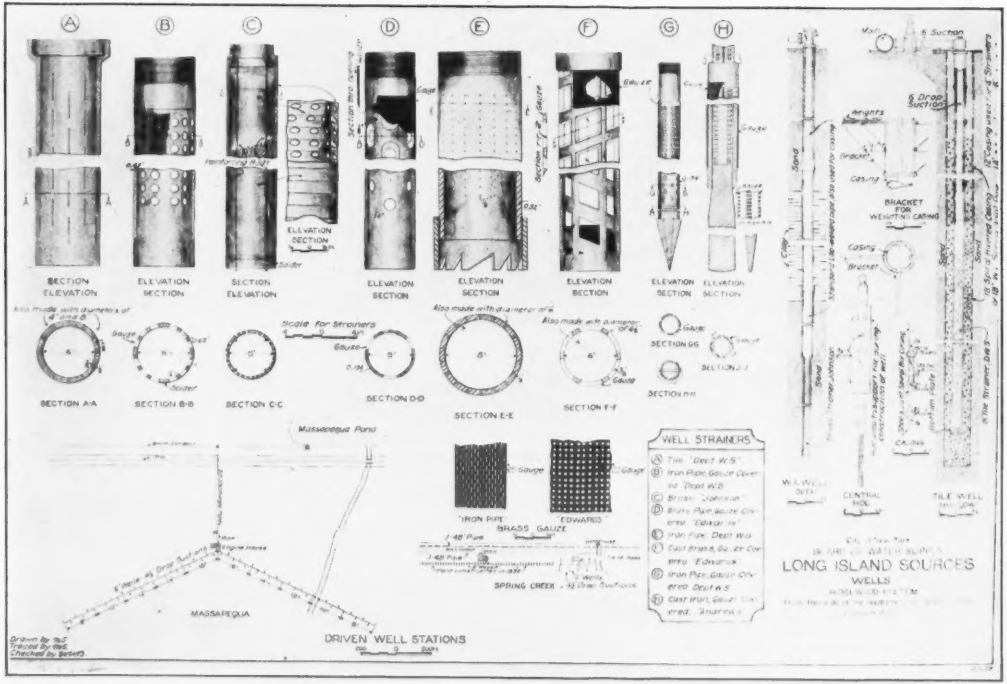
Suffolk County line, the watershed area being about 159 square miles. The watershed consists mainly of a sandy outwash plain several hundred feet in depth, the surface sloping gently upward from the salt water bays northerly to a ridge of hills formed by a glacial terminal moraine, the surface rising rather sharply in the central part of the island to an elevation which is, in general, somewhat less than 200 feet above sea level.

The conditions on this watershed are the exact opposite of those on the Croton shed, where storage of water on the surface is the economical method of obtaining a large percentage of the rainfall. On the Brooklyn watershed the storage of a large quantity of water on the surface is practically impossible, due to the pervious soil and slight changes in ground level, and there is only one supply reservoir that holds over 50 m. g., this being known as the Hempstead Storage Reservoir, built in 1870–1875, just south of the town of Hempstead, and containing about 880 m. g. with a flow line at elevation of 30, this being equivalent to a depth of about 19 feet at the dam, which is of earth with a clay core wall.

The supply from the Brooklyn shed is derived mainly from small streams on which shallow ponds have been formed, and from driven wells and infiltration galleries drawing on the sub-surface waters. This form of development is due to the geological character of the watershed, which, on account of its sand and gravel formation, absorbs nearly all the rainfall, amounting to about 43.5 inches yearly. The rainfall which does not evaporate and is not used for vegetation passes slowly through the upper sands to the saturated bed and then flows slowly toward the sea, this rate of flow being usually less than a mile per year. The saturated water-table is an almost uniform plane, sloping at an average rate of approximately 10 feet per mile toward the sea, this slope being a maximum near tide water and a minimum in the central part the island. Where the land surface dips below the water-table, a small stream is formed, which is fed by both surface run-off and sub-surface flow. It is estimated that each year about 14 inches of rainfall flow through the streams and about 12 inches pass out to the bays and ocean through the sands and gravels. Beds of clay of a thickness varying from a few inches to about 50 feet, and of irregular shape and area, divide the underground flow into several strata.

Taking advantage of the natural stream and reservoir of filtered water that underlie the south side of Long Island, the supply from the surface streams has been supplemented and, to a large extent, supplanted in recent years by the sub-surface development.

The first sub-surface development consisted of an open brick well about 50 feet in diameter, but this was not successful in adding materially to the supply. In 1882 groups of 2-inch wells, located about ½ mile from tide water where the water level was at elevation of 5 to 10 feet, were driven to a depth of about 40 feet and connected to a central suction pipe about 700 feet in length laid at approximately the ground water level. From 100 to 150 of these wells, with strainers 5 to 7 feet in length formed by soldering perforated brass sheets over ribbed-iron frame, were driven for each station, and by lowering the water level from 10 to 15 feet a supply of from 2½ to 5 m. g. d. could be obtained. The well system was later modified by increasing the diameter of the wells to from 4½ to 8 inches, lengthening the strainers to from 10 to 20 feet, and reducing the number of wells. The strainers were made of solid brass, brass frame covered with perforated brass, and iron frames covered with brass. Wells surrounded by gravel were also tried, a casing about 6 inches larger than the well being sunk and refilled for about 3 feet with gravel. The well strainer was lowered until the bottom rested on the gravel, and then gravel was placed around the well and the casing withdrawn. Both metal and vitrified pipe wells were constructed in this manner and gave an increased discharge and lasted longer than the wells without gravel. As a great deal of trouble was occasioned by the clogging of the wells, and the small stations were inefficient and expensive in maintenance and operation, it was decided to construct two infiltration galleries, known as the Wantagh and Massapequa gallery stations. These galleries consist of vitrified tile pipe, laid at right angles to the line of flow and from 10 to 15 feet below the normal water level. The Wantagh station consists of a central station with a brick pump well, 18 feet in diameter, with bottom at elevation of —10. Pipes 36 inches in diameter, with open joints and surrounded by gravel, are laid each way from the well, commencing with invert at elevation —5.0. The pipes gradually reduce to 20 inches at the ends, and grade of invert rises to elevation of —2.0. The



WELLS USED IN THE RIDGEWOOD SYSTEM, BROOKLYN.

PLATE IV.

TABLE No. 3.

Sources of Supply, Borough of Brooklyn.

Municipal Works.

Designation.	Source of Supply.	Average Amount Furnished, 1908. M. G. D.	Year First Utilized.
New Utrecht Station	Driven wells	1.1	1885
Gravesend Station	,, ,,	3.2	1891
Canarsie Station	,, ,,	Completed in 1909; supply about 3 m. g. d.	1909
New Lots Station	,, ,,	6.9	1881
Spring Creek Station	,, ,,	4.1	1882
Woodhaven Station	,, ,,	3.1	1907
Aqueduct Station	,, ,,	3.1	1906
Shetucket Station	,, ,,	1.9	1897
Oconee Station	,, ,,	3.6	1897
Morris Park Station	,, ,,	2.2	1907
Baiseleys Station	,, ,,	0.9	1883
Jameco Station	Driven wells and Baiseleys Pond	10.6	1891 1858
St. Albans Station	Driven wells	2.0	1905
Springfield Station	,, ,, and pond	2.6	1897 1881
Rosedale Station	,, ,,	2.7	1906
Forest Stream Station	,, ,, and pond	5.2	1885 1860
Clear Stream Station	,, ,,	3.3	1885
Watts Pond Station	,, ,, and pond	4.2	1894 1881
Valley Stream Pond	Stream	Included below	1860
Lynbrook Station	Driven wells	0.6	1907
Smiths Pond Station	Pond	7.9	1872
Pines Pond	Stream	Including Valley Stream	1860
Shodack Brook	,,		1873
Hempstead Storage Reservoir	,,		1874
,, Pond	,,	5.7	1860
Millburn Station	Pond	*	1891
East Meadow Pond	Stream	*	1891
Agawam Station	Driven wells	1.1	1896
Merrick Station	,, ,,	1.7	1896
Newbridge Pond	Stream	*	1891
Matowa Station	Driven wells	1.3	1896
Wantagh Pond	Stream	*	1891
,, Infiltration Gallery Station	Infiltration gallery	8.2	1905
,, Driven Well Station	Driven wells	0.02	1896
Massapequa Pond	Stream	*	1891
,, Driven Well Station	Driven wells	0.2	1896
,, Infiltration Gallery Station	Infiltration gallery	15.0	1906
*Five ponds (see above)	Streams	32.2	1891

TABLE No. 3.—*Continued.*

SOURCES OF SUPPLY, BOROUGH OF BROOKLYN.

Private Plants.

Designation.	Source of Supply.	Average Amount Furnished, 1908. M. G. D.	Year First Utilized.
Titus 6th Street Station	Driven wells	2.8	1908
" Forest Park Station	" "	Under construction	
Flatbush Water Company's Station	" "	10.0	1882
Blythebourne Water Company's Station	Driven wells in bottom of open well	2.0	1891
German American Real Estate Company's Station	Driven wells	0.5	1891
Queens County Water Company's Station	" "	3.1	1903

The Titus plants deliver directly into the municipal distribution system, and the Queens County Water Company delivers into the conduit near Valley Stream.

total length of the gallery is slightly over 12 000 feet. The ground water level normally stands at elevation varying from 5 to about 13, and, by lowering the water level in the pump well to about elevation —6, a supply averaging 12 m. g. d. can be obtained. The galleries, therefore, yield an average of 1 m. g. d. per 1 000 feet of pipe. The cost for construction is approximately $15 per linear foot. The Massapequa station is similar in design to the Wantagh station, the total length of gallery being 18 000 feet.

The supply from the eastern section of the watershed, amounting to from 60 to 70 m. g. d., is drawn from five streams, five driven well stations, and two galleries. This supply is carried, by gravity, through a brick conduit of horseshoe shape, varying from 5 feet 11 inches by 7 feet 4 inches at the east end to 6 feet 11 inches by 9 feet 4 inches at the west end. The water is delivered to an intermediate pumping station, known as the Millburn station, located near one of the supply ponds just east of Baldwin, Long Island. Here the water is raised from elevation 5 to a pressure equivalent to an elevation of about 60 and forced into three 48-inch mains, two of which carry the water to the main

pumping station located in the northeast section of the borough known as the Ridgewood station. The third 48-inch main is about 8 400 feet in length and then connects to a 36-inch main 7 600 feet long which discharges into the upper end of the brick conduit built as part of the original works. This conduit runs through the westerly part of the watershed and carries the water, by gravity, to the Ridgewood station. Eleven small driven well stations, four combined pond and driven well stations, one pond pumping station, and five ponds, deliver their supply into this conduit. The conduit is of varying dimensions increasing in size from 6 feet 4 inches by 8 feet 2 inches at the east end to 8 feet 8 inches by 10 feet at the west end. A 72-inch steel pipe, $\frac{7}{16}$ to $\frac{5}{8}$ of an inch thick, is now being laid parallel to the existing conduits, so that about 50 m. g. d. can be forced directly into the distribution system from pumping stations on the east end of the watershed. At the Ridgewood station about 120 m. g. d. is pumped from an elevation of about 7 into the low service, which is fed by the Ridgewood distributing reservoir, having three basins with the flow line at elevation 170, and a total capacity of 304 m. g. About 10 m. g. d. is pumped into the Mt. Prospect Reservoir, which has its flow line at elevation 198, and a capacity of 20 m. g. The higher ground, which rises to a maximum street level of about 170 is supplied from the Mt. Prospect Tower, with its overflow at elevation 278, being fed by the Mt. Prospect pumping station located at the corner of Underhill Avenue and Prospect Place, a few blocks from the entrance to Prospect Park. This station obtains its supply from the Ridgewood service mains and pumps about 7 m. g. d. for the Mt. Prospect Reservoir supply and 7 m. g. d. for the tower supply. The tower and reservoir are located just east of the main entrance to Prospect Park.

There are four driven well stations within the borough limits that pump about 15 m. g. d. directly into the city's mains against the Ridgewood pressure.

The distribution system consists of about 870 miles of mains from 4 to 48 inches in diameter, with about 14 000 gates and 13 000 hydrants. There are about 145 000 taps, of which about 14 000 are metered. The total average daily consumption is about 145 m. g. d. for a population of 1 440 000, or 98 gallons per capita.

The total cost of the Brooklyn system has been slightly over $30 000 000.

Three driven well stations, owned by private companies and furnishing about 12 m. g. d., supply a portion of the borough.

There are two high pressure fire service systems in Brooklyn. The main system was installed in 1905–7, and protects a business and manufacturing district along the East River, running from the Erie Basin to the Navy Yard, and extending back approximately one mile from the river front. This area comprises about 1 400 acres. The supply is furnished by two stations, the main station being located on the river front at the foot of Joralemon Street and the reserve station opposite Fort Greene Park at the corner of Willoughby and St. Edward streets. The main station can draw its supply either from the Ridgewood mains or the East River, and the reserve station from the Ridgewood mains. The equipment of the station consists of Worthington motor-driven 6-stage turbine pumps, delivering 3 000 gallons per minute, against a pressure of 300 pounds per square inch. The pressure is controlled by Ross regulating valves, and the stations are usually run with a pressure of about 150 pounds. The main station has five units, or a capacity of 15 000 gallons per minute, and the reserve station, three units, or a capacity of 9 000 gallons per minute. The pumps exceed their rated capacities, especially at pressure below 300 pounds. The total cost of the installation, which, in addition to the stations, includes about 21 miles of 12 to 20-inch mains, 1 000 gates, and 730 hydrants, was about $1 300 000. Extensions are soon to be made to the pipe system at an estimated cost of $750 000.

The Coney Island high pressure system was installed in 1904–5, and protects the amusement section of Coney Island. The pumping station is located on Coney Island Creek, opposite West 12th Street, and can obtain its supply either from the Ridgewood system or from a salt water creek. The equipment of this station consists of three Nash gas engines, connected to Goulds triplex pumps, each unit having a capacity of 1 500 gallons per minute against a pressure of 150 pounds per square inch. The total cost of installation, including about 1.2 miles of 12- to 16-inch mains, with 61 gates and 47 hydrants, was about $100 000. Extensions to the system are now under way, the estimated cost being about $150 000.

Designation.	Area Supplied.	Consumption. M. G. D.	Name.
Ridgewood low service.	All the borough except high ground near Eastern Parkway, Prospect Park, Greenwood Cemetery, Sunset Park, Clinton Ave., Heights sections, and territory of private companies.	120	Ridgewood Reservoir (3 basins).
Mt. Prospect Reservoir.	Territory between about elevation 70 and elevation 110, in vicinity of Eastern Parkway, Prospect Park, and Clinton Ave. and Heights sections.	15	Mt. Prospect Reservoir.
Mt. Prospect Tower.	Territory above about elevation 110, in vicinity of Prospect Park, Greenwood Cemetery, and Sunset Park.	7	Mt. Prospect Standpipe.
Flatbush Water Co.	29th Ward.	10	Standpipe.
Blytheborne Water Co	Blytheborne and Borough Park.	2	Four tanks.
German-American Real Estate Co.	Small section in east New York.	½	Standpipe.

TABLE No. 4.

Distribution Services, Boroughs of Brooklyn.

Municipal.

Reservoirs and Standpipes.						Pumping Stations.			
	Location.	Source of Supply.	Elevation of Nominal High Water. Feet.	Depth. Feet.	Capacity. M. G.	Name.	Location.	Source of Supply.	Pumpage. M. G. D.
						Ridgewood, Old and New Stations.	North and south side of Atlantic Ave. near Logan St.	Wells, infiltration galleries and streams on south side of Long Island.	120
ervoir	Cypress Hills Ave. near easterly end of borough.	Ridgewood Pumping Station.	170	20	304	New Lots.	New Lots Road and Fountain Ave.	Wells.	7
						Gravesend.	Ave. S and E. 17th St.	"	3
						New Utrecht.	Neck Road and E. 15th St.	"	2
						Canarsie.	E. 92d St. and Ave. D.	"	3
						Titus, 6th St.	6th St. and 4th Ave.	"	3
Reser-	Near main entrance, Prospect Park.	Ridgewood and Mt. Prospect Pumping Stations.	198	20	19	Ridgewood, Old Station.	See above.	See above.	10
						Mt. Prospect.	Underhill Ave. and Park Place.	Ridgewood low service.	5
Stand-	Adjoins reservoir.	Mt. Prospect Pumping Station.	278	75	0.11	Mt. Prospect.	See above.	" "	7

Private.

	Franklin and Washington Aves.	Pumping Station.	180	102	0.24	Flatbush Water Co.	Paerdegat Creek, east of Flatbush Ave.	Wells.	10
	11th Ave. and 74th St.	Pumping Station.	140	..	0.10	Blytheborne Water Co.	Same as tanks.	"	2
	Pennsylvania Ave. south of New Lots Road.	Pumping Station.	...	..	...	German-American Real Estate Co.	Same as standpipe.	"	0.5

The Brooklyn water works system is under Mr. Walter E. Spear, chief engineer.

BOROUGH OF QUEENS.

The borough of Queens obtains its supply from a number of small driven-well stations, these stations having been built, as a rule, to supply the various separate communities which are now consolidated into one borough. There are 6 municipal plants and about 17 private plants owned by 7 companies. These plants are all comparatively small, the total supply for the borough being about 25 m. g. d.

TABLE No. 5.

SOURCES OF SUPPLY, BOROUGHS OF QUEENS AND RICHMOND.

Designation.	Source of Supply.	Average Amount Supplied. M. G. D.
Queens — Municipal.		
Long Island City, No. 1	Wells	0.8
" " " " 2	"	0.8
" " " " 3	"	0.6
Flushing	"	1.6
Bayside	"	1.2
Whitestone	"	0.4
Queens — Private.		
Citizens' Water Company, eight stations	Wells	12
Jamaica " " two "	"	3
Queens " "	"	2.5
Woodhaven " "	"	2
Bowery Bay Imp't Company	"	0.5
Montauk Water Company	"	1.5
Woodside " " three stations	"	Not in use
Richmond — Municipal.		
Tottenville	Wells	0.3
Three stations for West New Brighton, etc.	"	4
" " " Stapleton, etc.	"	3.7
Richmond — Private.		
South Shore Water Supply Company	Wells	0.2

These stations pump directly into the distribution mains and usually have a standpipe connected to the system. The amount delivered is estimated on pump displacement.

BOROUGH OF RICHMOND.

The supply of this borough is obtained from eight driven well stations, of which one plant has been owned by the city for several years, the remaining plants, with exception of a very small system, having been recently acquired by the municipality. The supply obtained from these plants, which amounts to about 8 m. g. d., is inadequate to serve the borough, the population of which is about 80 000. A contract has been made with a private company for an additional supply of from 3 to 10 m. g. d., to be obtained from New Jersey, this contract to run for ten years.

ADDITIONAL SUPPLY.

The safe supply from the systems utilized for all the boroughs, with the possible exception of the borough of Queens, is hardly sufficient to meet the requirements of the consumers during a period of drought of a severity equal to that which has been experienced in the past. This has been the condition for several years, the increase in supply obtained by the construction of new reservoirs on the Croton watershed and the additional development of the underground supply of Long Island, west of Suffolk County, hardly keeping pace with the increase in consumption, and further permanent relief from such development is impracticable.

Upon completion of the Croton Falls Reservoir now under construction, the then available supply and the present consumption may be estimated as follows:

Borough.	Safe Minimum Supply. M. G. D.	Average Daily Consumption. M. G. D.
Manhattan, Bronx	350	330
Brooklyn	150	155
Queens	40	25
Richmond	7	8
Total	547	518

The present margin of safety is so small that it will be used up by the increase in consumption in a year or so. The consumption would probably have been in excess of the safe supply before now had it not been for the abnormally low consumption caused, in part, by the general business depression.

In 1899, alleging that the supply was then inadequate, an attempt was made by certain city officials to enter into a contract with a private company to supply 200 m. g. d. at a cost of $70 per million gallons, this contract to run for a period of forty years. The opposition to this contract resulted in careful investigations of the present and future supply, and two extensive reports, one to the then Comptroller, Bird S. Coler, by Mr. John R. Freeman, dated March 23, 1900, and the other to the Merchants' Association, made in 1900 by its Engineering Committee, of which Mr. Thomas C. Clark was chairman. These reports condemned the proposed contract, and were followed about two years later by an exhaustive examination and report made by the Commission on Additional Water Supply, composed of Messrs. William H. Burr, Rudolph Hering, and John R. Freeman, this report being submitted under date of November 30, 1903.

As a result of the evident and urgent need of an additional supply, and in accordance with the recommendations of Mayor George B. McClellan, the creation of the Board of Water Supply to construct the necessary works was authorized by the legislature in 1905. At the same time the State Water Commission was created, to control the water resources of the state. In June, 1905, the Mayor appointed Messrs. J. Edward Simmons, Charles N. Chadwick, and Charles A. Shaw as the three commissioners to form the Board. Mr. Simmons, who was the president of the Board, resigned in January, 1908, and was succeeded by Mr. John A. Bensel; Mr. J. Waldo Smith was appointed chief engineer; Mr. John R. Freeman, consulting engineer to the Board; and Messrs. William H. Burr and Frederick P. Stearns, consulting engineers to the chief engineer.

A report was made by the Board of Water Supply to the Board of Estimate and Apportionment on October 9, 1905, recommending the development of four watersheds in the Catskill Mountains as the most available sources of supply, with sufficient conduit capacity to deliver 500 m. g. d. to the city, at a total cost of about $162 000 000, exclusive of delivery of the supply for the boroughs of Manhattan and the Bronx, the cost including works to deliver 100 m. g. d. to Queens and Brooklyn and a connection to Richmond. It was considered that the expenditure of $112 000 000

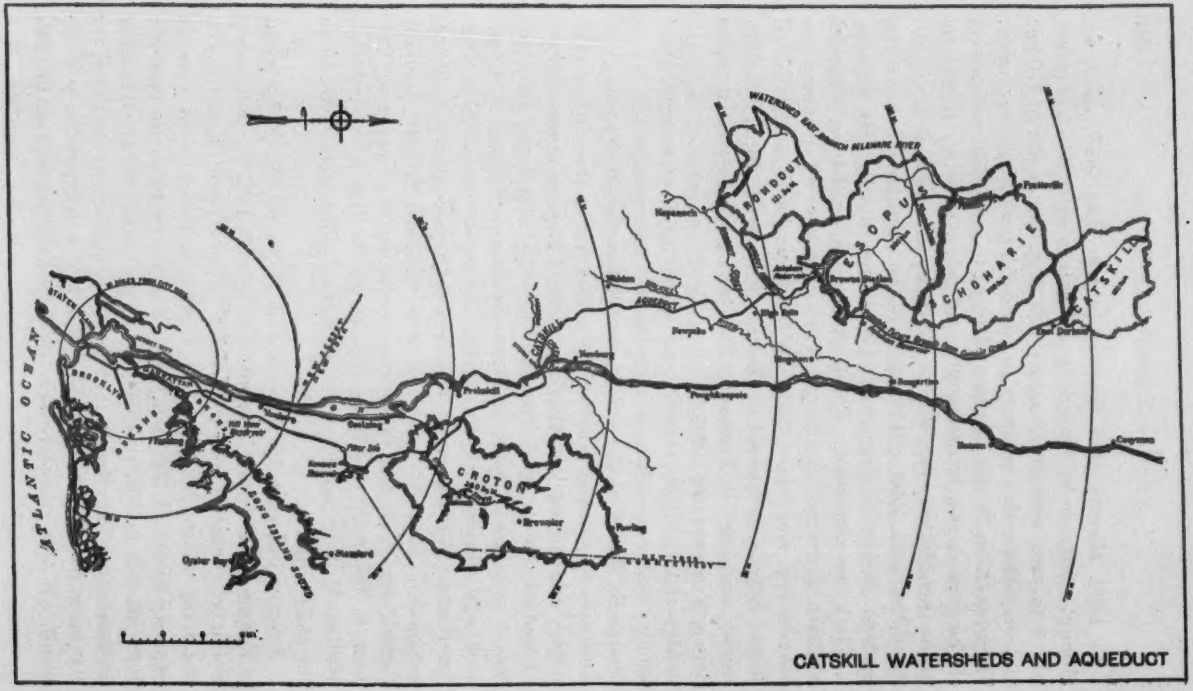


FIG. 5. OUTLINE OF THE CATSKILL SYSTEM.

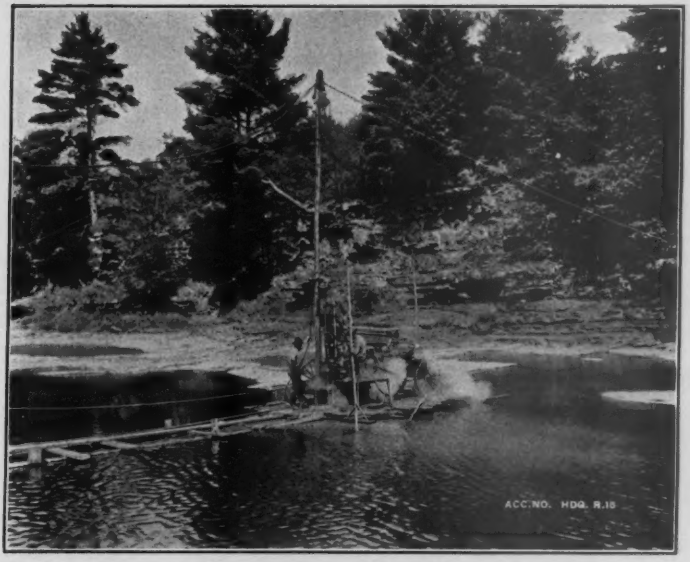


FIG. 1. BORING RIG IN ESOPUS CREEK AT THE OLIVE BRIDGE DAM SITE.

FIG. 2. OLIVE BRIDGE DAM, LOOKING UP STREAM.
Showing dam under construction and two 8 ft. steel pipes used for river control.

would be sufficient to develop a supply of 250 m. g. d., the additional 250 m. g. d. being developed later, as required. Recommendation was made that the Long Island watersheds be studied, with a view to their development as the most available source of supply for the immediate needs of Brooklyn, Queens, and Richmond boroughs. The plan proposed was approved by the State Water Commission and work is now actively in progress, the expenditures to date, together with estimated cost of work under contract, amounting to over $50 000 000.

The watersheds adopted for the supply consist of Esopus, Rondout, Schoharie, and Catskill creeks. The waters of the Schoharie Creek are to be delivered by tunnel into the valley of the Esopus Creek, branch aqueducts being planned to convey the Rondout and Catskill creek waters to the main aqueduct. An enormous reservoir, known as the Ashokan Reservoir, is to be developed in the Esopus valley. From this reservoir an aqueduct to deliver 500 m. g. d. is to be built, consisting of cut-and-cover, grade tunnel, pressure tunnel, and pipe siphon sections. A large receiving and storage reservoir is to be constructed on the east side of the Hudson River on the site of the existing Lake Kensico. An equalizing reservoir is to be constructed on the high ground just north of Van Cortlandt Park, the water being carried from this reservoir in pressure tunnel to the boroughs of The Bronx, Manhattan, and probably Brooklyn, and by pipe lines to the boroughs of Queens and Richmond.

The Ashokan Reservoir will receive the drainage of about 257 square miles of watershed on the Esopus Creek and about 228 square miles on the Schoharie Creek. Its flow line is to be at elevation of 590 feet. The reservoir is to be divided into two basins, having a total capacity of 128 000 m. g., flooding an area of about 12.8 square miles, and having a shore line of about 40 miles. The main dam is to be a masonry structure across the Esopus Creek, 1 000 feet long at the top and having a maximum height of 240 feet. Additional dams and dikes will have to be constructed of a total length of over 5 miles. The aqueduct is to be of concrete of varying dimensions, depending upon whether it is of cut-and-cover, grade tunnel, or pressure tunnel type. The hydraulic gradient at Ashokan Reservoir is to be at elevation of 510,

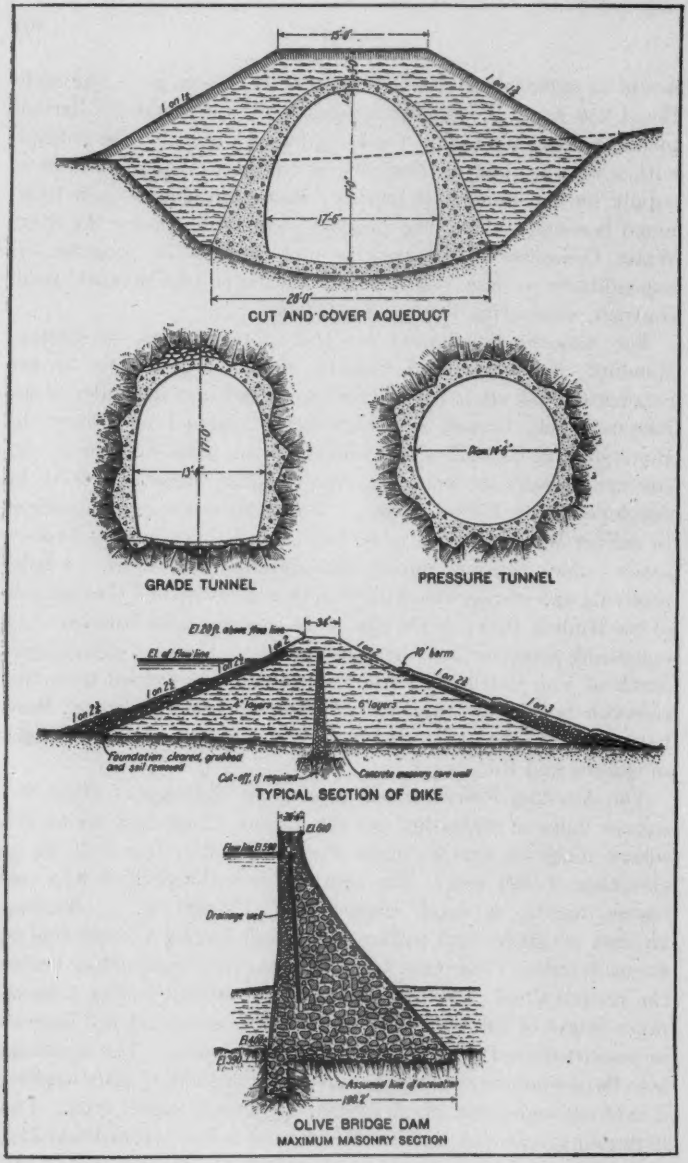


FIG. 6. SECTIONS OF THE CATSKILL AQUEDUCT, TYPICAL DIKE AND OLIVE BRIDGE DAM.

CATSKILL AQUEDUCT — Full-Size Concrete Model of Aqueduct as it will be built in Trench. Test section.

PLATE VI.

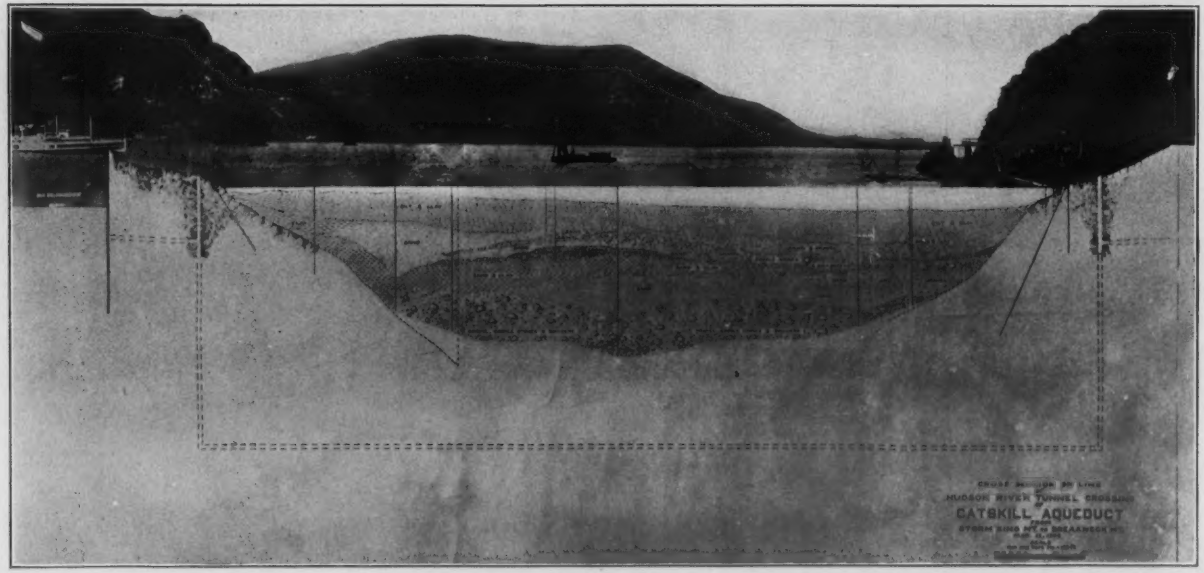
which will reduce to 355 at Kensico Reservoir, the gradient varying for the different types of aqueduct, being a maximum for the pressure tunnel sections and a minimum for the cut-and-cover section. At Kensico Reservoir there will be a drop of from 25 to 35 feet, and then a fairly uniform gradient to Hill View Reservoir, with its flow line at 295. The total length from Ashokan to Hill View is 91 miles, of which 54.2 miles is to be cut-and-cover type; 13.4 miles, grade tunnel; 17.2 miles, pressure tunnel; and 6.3 miles, steel siphon. From Hill View to Brooklyn the tunnel will be over 16 miles, with 11 miles of pipe to reach Richmond. The cut-and-cover section, which is the largest in area and the lowest in cost per foot, is 17 feet high, with a maximum width of 17 feet 6 inches. The grade tunnels are usually 17 feet high by 13 feet 4 inches wide. The pressure tunnels are circular and vary from 14 feet to 16 feet 6 inches in diameter. The pipe siphons for crossing valleys where the geological conditions are unfavorable for pressure tunnels are to be of steel covered with concrete and lined with cement mortar, the clear inside diameter being from 9½ to 11 feet. The lowest level to which the pressure tunnels have to be driven will be at the Storm King crossing of the Hudson River, where it is expected to go about 1 200 feet below the water level to obtain satisfactory rock for the tunnel. These pressure tunnels, both in size and pressure to which they will be subjected, far exceed any previous tunnels constructed for water works and constitute one of the prominent features in the design of the works.

The Kensico Reservoir is to have a capacity of about 40 000 m. g., with a water surface 355 feet above tide. It is designed as a storage reservoir to be used when the aqueduct north of the reservoir is cut out of service for examination or repairs. The dam for this reservoir is to be of masonry, about 1 830 feet long and nearly 300 feet from the crest to the deepest part of the foundation.

The Catskill aqueduct will deliver its water into the Hill View Reservoir, which will be used as an equalizing basin and will hold approximately 900 m. g. The flow line is to be 295 feet above tide, the depth to be 36.5 feet, and the water surface about 3 000 feet by 1 500 feet. A central wall in which is constucted a bypass aqueduct will divide the reservoir into two basins. South of the reservoir it is expected to construct a pressure

tunnel under the borough of The Bronx, crossing the Harlem River just below High Bridge, running through the borough of Manhattan, and crossing into Brooklyn under the East River just below the Navy Yard. This tunnel is to be of sufficient size to carry the supply delivered by the Catskill aqueduct, and borings are now being made to determine the character and elevation of rock that is to be penetrated. The use of a pressure tunnel for distributing water for a large city is rather unusual, although the Croton pressure tunnel is a precedent in the city of New York. Connections at the various shaft sites to the pipe system are to be provided for the delivery of the Catskill water into any part of the boroughs of Manhattan and The Bronx. For Brooklyn and Queens, large pipes will be required, as the conditions are not favorable for economical extension of the tunnel system. For the borough of Richmond, submerged pipe lines are to be laid across the Narrows, and a reservoir constructed to equalize the pressure and safeguard the supply for this borough. Upon completion of the Catskill works, the city of New York will, with its present sources, have a water supply of over 1 000 m. g. d., of excellent quality, the quantity far exceeding that used by any other municipality in the world.

The Board has carried on extensive preliminary surveys and investigations to determine the available supply from the undeveloped watersheds of Long Island, and last year recommended that the south and easterly sections of Suffolk County be utilized for Brooklyn, Queens, and Richmond by drawing from the subsurface flow. The conclusions of the Board as to the watershed to be developed agree practically with those reached by Mr. I. M. de Varona, at present chief engineer of the Department of Water Supply, Gas, and Electricity, borough of Manhattan, in a report on the additional water supply for Brooklyn, submitted in 1895, although the methods to be followed are different. The Board of Estimate and Apportionment approved, in 1908, the utilization of this source of supply, and the State Water Commission was requested to authorize its development for New York City. Opposition was encountered from owners of large estates within the watershed, and the State Commission has not yet given its approval.



STORM KING CROSSING FOR CATSKILL AQUEDUCT.

PLATE VII.

The Catskill works, which are second only to the Panama Canal in magnitude, are being carried on, as has previously been stated, under the direction of Mr. J. Waldo Smith, chief engineer, with Mr. Charles L. Harrison, deputy chief engineer. The work has been divided into four engineering departments, i. e.: Headquarters, Mr. Alfred D. Flinn, department engineer; Reservoir, Mr. Carleton E. Davis, department engineer; Northern Aqueduct, Mr. Robert Ridgway, department engineer; and Southern Aqueduct, Mr. Merritt H. Smith, department engineer. Under these engineers, a corps of nearly 1 000 men are engaged on the surveys, design, and construction of these works, to build which will require the employment of probably 15 000 men, and an expenditure for a time of $2 000 000 per month. While these figures seem stupendous, they give a fair idea of the magnitude of the work that New York City has undertaken to insure an ample supply of water for the next generation.

In preparing this description of New York City Water Works the writer has drawn freely from published reports and papers, it being impossible to acknowledge his indebtedness to the individual authors. He wishes to acknowledge the assistance given by the Board of Water Supply in furnishing lantern slides, maps, and data; to Mr. I. M. de Varona, chief engineer, and Mr. H. B. Machen, assistant engineer, Department of Water Supply, Gas, and Electricity, for slides; and Mr. Arthur S. Tuttle, engineer of public improvements, Board of Estimate and Apportionment, for slides, without whose assistance it would have been impracticable to give the illustrations of both the present and new water works systems.

DISCUSSION.

MR. WILLIAM DART. Will Mr. Brush please tell us something about how the dikes are constructed, particularly as to whether any artificial method of excavation, such as pumping, is used. When work is carried on at such a rapid rate, it is very difficult to obtain the proper solidity, and we often hear of accidents due to that cause. I should like also to ask Mr. Brush whether the dams are kept at a restricted height, so that, say, not more than one foot is raised at a time, and, if the method of pumping is used, what time is allowed for proper solidification of the earthwork.

MR. BRUSH. Those are questions which I think can be better answered by some of the other engineers, for I am not connected with that part of the work, and am, therefore, not familiar with the details of construction. Probably Mr. Flinn, our department engineer, can give the gentleman the information desired.

MR. ALFRED D. FLINN. In answer to Mr. Dart's question, I will say that the material available for making the dikes at the Ashokan River Reservoir is particularly suitable for the purpose, being a clay which compacts very solidly. The banks are being built up in layers of varying thickness. On the water side the layers after compacting are about four inches thick, and on the other side about six inches thick. Each layer is spread and rolled, and there is no deposit of earth by any pumping method. It is all done by bringing the earth on to the bank in cars or wagons, spreading it and rolling it, and the banks are kept approximately level in any particular section.

MR. EDWARD W. BEMIS.* I wish Mr. Brush would explain a little more as to what he meant by legislative restrictions preventing the development of a supply east of the Hudson River.

MR. BRUSH. The legislature passed one or more acts prohibiting the use of those watersheds which lie just north of the city and east of the Hudson. Those sources were considered and reported upon favorably by the Additional Water Supply Commission, but subsequently to that report the legislature passed acts prohibiting the utilization of those watersheds for a public water supply for New York City on account of the opposition, as I understand, from the inhabitants of that section, and also from those who are using the water power, against New York City taking those sources for a supply. It would have been cheaper to have used this supply, but these acts prevent it.

DR. JOHN C. OTIS.† I might say, in addition to what Mr. Brush has said, that there are several manufacturing interests, of not very large capacity, along the course of those streams in Dutchess County, and it was thought that their business might be ruined if the water was taken. The great majority of the people of the county were very much opposed to any legislation restricting New

* Superintendent Water Works, Cleveland, Ohio.
† Poughkeepsie, N. Y.

York from taking those watersheds, but the manufacturers had influence enough in the legislature to secure the passage of the acts. We consider that it was a very unfortunate thing for Dutchess County as well as for New York.

MR. MICHAEL F. COLLINS.* In Mr. Brush's paper the statement is made that the fire service in New York is connected both with salt water and with the city supply water. Will Mr. Brush please tell us what objection there is to using salt water entirely?

MR. BRUSH. The use of salt water is detrimental to the valves, and also, to some extent, to the pipe, and I understand that a greater amount of damage would be caused to merchandise by salt water than by fresh water where a fire does not entirely destroy a building. The amount of water required for fire purposes for the entire city for a year is only about one fifth of a day's supply, and, therefore, is negligible in quantity, and as the use of salt water would probably cause a rather rapid corrosion in the valves, where there is bronze in contact with iron, and also a much less rapid, but still a somewhat rapid, deterioration of the iron pipes, it was considered advisable to use fresh water, and only have the salt water for an emergency supply. The valves and hydrants were designed to use salt water if necessary, and to minimize the corrosion that might be experienced by the use of salt water, but in view of the fact that fresh water was available and such a small amount relatively would be used, it was considered advisable to use fresh instead of salt water.

MR. BEMIS. What effect does it have on the pressure supply mains when you take so much water for a fire, and what size mains do you tap?

MR. BRUSH. In Brooklyn the main station obtains its supply from two 48-inch and one 30-inch mains, the water passing to the station through 24-inch and larger connecting mains, the connections at the station consisting of two 24-inch branches. For the reserve station, a 48-inch and a 30-inch main are connected to the station suction main through two 20-inch branches.

In the borough of Manhattan, the Oliver Street station obtains its supply from three 36-inch and one 30-inch mains, having two 30-inch connections to the station. The Gansevoort station ob-

* Superintendent of Water Works, Lawrence, Mass.

tains its supply from one 48-inch, three 36-inch, and one 24-inch mains, with one 30-inch and one 36-inch connection to the station. In each case there is a loop system of supply so that two or more distribution mains are connected to the station, and also a loop delivery system, so that an accident to any part of the system would only cut out a very small section. As far as I know there has never been any appreciable effect by the draft on the mains from the high-pressure stations, its being found that, with from three to four pumps running, the drop at the station is about six pounds. Normally, one pump is more than ample for a fire, and Manhattan has had three large fires at one time during the past season which were controlled by the high-pressure system without any difficulty, and it was not necessary to put into service but three or four of the pumps. If the ten pumps were running, they would require 30 000 gallons a minute, or about 42 000 000 gallons a day, and such a draft would undoubtedly reduce by several pounds the pressure in down-town Manhattan.

GROUND WATERS AS SOURCES OF PUBLIC WATER SUPPLIES.

BY WILLIAM S. JOHNSON, CONSULTING ENGINEER, BOSTON, MASS.

[*Read November 10, 1909.*]

When the average man deals with the unseen, he apparently believes that he is dealing with the supernatural and that the ordinary laws of nature do not apply, or perhaps he goes to the other extreme and builds up an elaborate theory of which he would be ashamed were he dealing with the seen. Such has certainly been the case in dealing with ground waters. Many a man of good sound common sense, who would look with scorn upon any attempt to show that water on the surface of the ground could exercise any attraction for the witch-hazel stick, has without question accepted the theory that water a few feet beneath the surface of the ground, because out of sight, has a power which is not possessed by the same water when it appears on the surface.

On the other hand, many pages of intricate formulas have been published by accomplished scientists treating of the movement of ground waters through soils, when one glance at some deep cut in a sandy soil, such as we have in New England, showing the innumerable strata of every conceivable kind of soil from clay to coarse gravel, with their varying thicknesses and directions, should be sufficient to show that in order to determine the behavior of water beneath the ground it would be necessary to first make an examination of every cubic foot of soil and a new formula for almost every inch. In fact, those of us who have had occasion to study the flow of water through carefully selected material in a sand filter know the absolute impossibility, or rather, the impracticability, of foretelling the result.

Many of you are familiar with the testimony of the eminent geologist a few years ago to the effect that the ground water supplies in eastern and southeastern Massachusetts were obtained from an underground river flowing from New Hampshire toward

the south, and that he had determined the course of this subterranean stream, which was somewhat circuitous, by means of the various public water supplies which had been obtained from the ground. The same geologist explained another water supply in Massachusetts as coming from a subterranean reservoir of water which had been left there in some prehistoric time.

There is no doubt that a theoretical study of the flow of water through soils has produced good results, and that a thorough knowledge of geology is essential to the engineer seeking for ground water supplies. Neither is there any doubt that the witch-hazel has produced good results. In the hands of the intelligent person it has located many excellent wells. It is necessary, however, to state in the beginning that the author is not going to reveal the secret of the witch-hazel, nor is he going to produce a new formula by which a ground water source can be found and its yield computed. The more the writer had seen of ground water supplies, and the more carefully he has studied them, the less confidence he has in his ability, or in the ability of any other person, to foretell what may be found in exploring a new field. With our present state of knowledge of things beneath the earth, experience is certainly the best guide, and experience has taught us many things with relation to ground water supplies, some of which are unknown to those who have not dealt very much with such sources. The object of the present paper is to bring out a few of these points.

Since the expert with the witch-hazel has to some extent been discredited, the expert well driver has taken his place to work upon the same weaknesses in human nature, the same willingness to believe that natural laws do not apply to things unseen, as did his predecessor. There are honest and intelligent well drivers, more now than a few years ago, but the temptation is so great, when business is poor and the mark is so easy, that many a well driver has fallen, and the results are to be found all over the country, where wells have been driven in solid rock, generally at the summit of some hill. There are certainly honest well drivers, for only recently a client who insisted, against the writer's advice, in drilling a well in solid ledge at the summit of a hill confessed that one of the well drivers whom he had consulted had also advised against

it, telling him that at least three out of four wells of this kind were failures. He found, however, two other well drivers who approved most heartily of his plan and were certain that an abundant supply of excellent water could be found by drilling deep enough, at five dollars per foot.

What is said in this paper applies to conditions existing in New England, and may or may not be applicable to other parts of the country; for it is, of course, a fact that the ground waters depend very largely upon the geological conditions, and what is applicable to New England is not necessarily applicable to other parts of the country.

Ground water supplies may be divided into those obtained from deep wells, or the so-called artesian wells, and those obtained from shallow wells, either driven or dug, or from filter galleries located near some surface source.

Concerning deep wells, or the so-called artesian wells, which are generally driven in rock, there is very little to say. They have been tried many times for public water supplies, but have very seldom been successful, but here again it is necessary to call attention to the fact that the author is speaking of conditions in this vicinity only, for there are sections of the country where the deep wells have certainly been very successful. The rock formation in this vicinity is of such a character that it is practically impossible to find a large quantity of water in it unless in some fissure of such a nature that the water passes directly through it from the surface of the ledge. Where a large volume of water has been found in this way, it has generally been of poor quality, but the most common failure is due to the small quantity obtainable.

It is a common belief that water obtained from the rock many feet beneath the surface must be of the greatest purity, but here again we expect something to happen beneath the surface which would not be possible above the surface, for nobody would maintain that the quality of water after passing through concrete, a channel of artificial rock, would differ greatly from the quality of the water entering this channel, and such is practically the condition when water enters a crevice in our granite or other hard rock. There are numerous examples of wells in rock which supply water for manufacturing purposes, and for these purposes they are fre-

quently satisfactory, but the writer knows of no case in Massachusetts at least where the deep well has been a success for a public supply, except, perhaps, where it has been used to secure a small additional supply to supplement some other source, and in each of these cases the water obtained from the deep wells has been of inferior quality. The most satisfactory water supplies are those which are obtained from shallow wells, either dug or driven, or from filter galleries, the water from which is obtained in every case either from the ground in the immediate vicinity or from some nearby surface source.

Water supplies a century ago were almost universally obtained from the ground, and still in the more sparsely settled districts the water supplies are obtained largely from wells. When the knowledge came that water might be the cause of typhoid fever, and the evidence seemed to be good that some serious epidemics had been caused by the water from wells, all wells came to be looked upon with disfavor, and many of them were closed by boards of health and other sanitary authorities, and public water supplies from surface sources were put in to take their places.

It was believed that the ground in the vicinity of dwellings was always saturated with filth which had been thrown upon or discharged into the ground for years, and that any water taken from the ground was unsafe. A great amount was written about the danger lurking in the well, the articles being generally illustrated by the familiar pictures showing by means of arrows the direct course taken by the filth from the cesspool or stable toward the well.

Now the pendulum has swung again, and again the discarded well is in favor, for we now believe that, when properly located, the well furnishes the best, or at least the safest, water, — far safer than the water of the mountain brook.

In 1879, of the 64 Massachusetts cities and towns supplied with water from public sources, 8, or 12 per cent., were supplied from ground water sources. In 1889 the percentage of cities and towns supplied from ground water sources was 31. In 1899 the percentage had reached 38, and now 41 per cent. of the cities and towns supplied with water obtain it from ground water sources.

Much of the increase in the use of ground waters in Massachu-

setts is due to the influence of the State Board of Health. In many cases the State Board of Health has advised against the use of some proposed surface water source and has urged that investigations be made with a view to securing a ground water supply. In some of these cases the ground water supply has been obtained at a considerable saving in expense, and in every case where the investigations have proved successful, water of a superior quality has been secured.

The chief reasons why ground water supplies are more satisfactory than surface sources for public water supply purposes are: *First*, their low temperature in summer; *second*, their attractive appearance and freedom from color, taste and odor; and *third*, the greater safety in their use.

The temperature of water obtained from the ground at the depth from which the supplies are ordinarily obtained is from 48 degrees to 52 degrees unless the water is affected to a considerable extent by the infiltration of surface water from some nearby surface water source, and this temperature is maintained throughout the year. Since ground waters must generally be kept from exposure to the sunlight on account of the growths of organisms which otherwise are likely to occur, the water is not stored in large, open reservoirs where it would become heated, and so is delivered to the consumers at a temperature which does not rise above 60 degrees, even during the warmest days in summer, and is never warm enough to be unpalatable. Surface waters, on the other hand, are frequently delivered to the consumers at a temperature of about 80 degrees.

A good ground water is always clear, practically colorless, odorless, and tasteless, while almost all surface waters are colored and are subject at times to disagreeable odors and tastes. The waters taken from mountain streams without being stored are the best of the surface waters in regard to color and odor, but these are very likely to be turbid at times of storms or of melting snow.

In the report of the Massachusetts State Board of Health for the year 1904 there is an interesting classification of the water supplies according to their different characteristics. In the classification of the surface waters according to their odors there are 32 in a total of 134 surface water sources which are classed as odorless,

or having occasional faint odors. Of these 32 sources which are nearly odorless, 20 are mountain streams, which in many cases are practically spring waters collected in a stream not far below the point at which the water issues from the ground, and should hardly be classed as surface waters.

In the classification according to color it is shown that of 141 sources classified, 22 have color less than 0.05, which may be considered practically colorless. Of these 22, several are ponds like Long Pond in Falmouth, Little South Pond in Plymouth, and Lake Pleasant in Montague, which are practically large open wells, being fed almost entirely from the ground.

It must be admitted that many ground waters have color, and some of them a very high color, but these are not normal ground waters, being affected in each case either by iron or by infiltration from some surface source.

The most important respect in which ground water is superior to surface water is in the comparative safety which attends its use. If the ground water source is properly located, even if the water has at some time been polluted, the danger in its use is reduced to a minimum. The purification effected in passing through soil at a rate as slow as water passes laterally through the ground is, we know now, very great, and it is almost impossible for disease germs to survive except under extraordinary conditions.

With the mountain streams, on the other hand, from which the most attractive surface waters are obtained, even if their watersheds are uninhabited, there is constant danger of pollution by the hunter, the fisherman, or in innumerable other ways. Any pollution entering such a stream is carried quickly and directly into the piping system and delivered to the consumers with no opportunity for the purifying effects of time or storage.

In case of ponds or storage reservoirs with uninhabited watersheds, the danger from pollution is less serious than in the case of streams, but there is always more or less danger, even with the most careful supervision of the source and its watershed. In addition to this there is the certainty of the fouling of the water by animals of various kinds, alive and dead, which, while perhaps not having a serious effect upon the health of those using the water, certainly makes the water less appetizing.

When we come to think of it, we must realize the absolute impossibility of securing water from the surface of the ground which shall be perfectly clean. There must be within the watershed of every surface source quantities of decaying organic matter from the leaves and other vegetation, as well as from animals, which will be washed into the water during every shower. In case of the pond or reservoir, purification by storage takes place, and the effect of this dirt is much less than in the case of the running stream, where there is little opportunity for the water to free itself from the impurities. Water taken from sand or gravel beneath the surface of the ground is generally absolutely free from any of this dirt.

The time is undoubtedly coming, and is not far distant, when all surface water supplies will be filtered before they are used for domestic purposes. The public is rapidly becoming educated in these matters, and it will soon be insufficient to know that the use of a water is not likely to give typhoid fever, and there will be a demand that the water shall be free from the filth which all surface waters contain in a greater or less degree.

The objectionable or troublesome features of ground waters are: *First*, the uncertainty which must exist as to the quantity of water available; *second*, the conditions which favor the growth of organisms in the water; *third*, the possibility of the presence of iron; and, *fourth*, the possible deterioration of the water with long-continued use.

The uncertainty as to the quantity of water is one which can be met only by making thorough tests. In the case of a surface water source it is possible to foretell with considerable accuracy the amount of water which the source will yield in a very dry season. In the case of a ground water supply it is impossible, even with as thorough a knowledge of the soil as it is feasible to obtain, to foretell the quantity of water obtainable.

In recent years it has been the custom in the most important investigations of ground water sources to make a pumping test to assist in determining both the probable quantity and the probable quality of the water to be obtained. The method of making these pumping tests will be referred to later. With the information furnished by the pumping test, especially if the test is con-

ducted during a period when the ground waters are at a low level, it is possible to make a sufficiently close approximation of the quantity of water available.

Ground waters, when exposed to light for a considerable time, are almost certain to contain growths of organisms, which, when they decay, will cause the water to be very objectionable. When the first ground water supplies were introduced, this fact was not known, and the water in many cases was stored in large open reservoirs. During the summer months the water in these reservoirs was affected by growths of organisms to such an extent that the water could hardly be used for domestic purposes. Such was the case in Newton, Brookline, Hyde Park, and several other of the Massachusetts cities and towns, and in all of these places it became necessary to provide covered reservoirs so that the water is not exposed to the light from the time it leaves the ground until it reaches the consumer. This not only prevents the growth of organisms, but it also perserves the low temperature of the water, which was not possible with the open reservoirs where the water was exposed to the sun.

Most of the troubles which have occurred with ground water supplies have been due to the presence of iron in the water. Iron occurs in ground waters in various forms, but in whatever form it occurs, the final result is the same. It causes rust spots on clothes which are washed in it, imparts to the water a color and an objectionable odor and taste, fills up service pipes, and clogs up the wells. In fact, there is nothing which causes so much complaint or trouble with a water supply as the presence of iron. It is not necessary at the present time to discuss the chemistry of the presence of iron in the water, but, in general, it may be said that the iron is the result of imperfect filtration of water containing organic matter.

It may be that the imperfectly purified water comes from some nearby surface source, or the water may have come through a deposit of peat from which it takes up organic matter, but in either case the presence of iron indicates that the water has not been completely purified in its passage to the well. Water obtained from a well sunk in a swamp where there is an extensive deposit of peat, with no impervious layer between it and the water-bearing

stratum, is almost invariably affected by iron. Water obtained from a well located close to a stream is likely to be affected by iron after long-continued draft from the well at a rate considerably greater than the rate at which water is flowing toward the well from the land side, since the filtration becomes less perfect, as more water is drawn from the surface source.

When the first ground water supplies were introduced, practically nothing was known as to the causes of iron in the water, and many of the wells or other collecting works were located in such a manner that they were soon affected by iron. In some of these cases it has been necessary to abandon the source, while in other cases filtration has been resorted to.

Good examples of the deterioration of ground water sources, due to the increase in the quantity of iron, are found in Hyde Park, Middleboro, Marblehead, Bradford, Provincetown and Reading. In Bradford and Provincetown the sources of supply were finally abandoned and water obtained from new sources; in Reading and Marblehead filtration has been resorted to.

There are numerous cases in Massachusetts showing the deterioration of ground water due to the increased amount of iron in the water, where the deterioration has been so slow that as yet comparatively little trouble has been experienced, and in some cases, as at Waltham, an apparently successful attempt has been made to check the deterioration by supplementing the supply from some other source so as to reduce the draft. Interesting examples of slow deterioration are found at Waltham and Lowell, where the deterioration is evidently due to increasing amounts of water being drawn from the river, or possibly to more rapid infiltration of water from the river.

In some cases the deterioration is due to the extension of the area from which the water is drawn to the collecting works with the increased draft from the wells. A case of this kind is found in Wellesley, where there is no pollution in the immediate vicinity of the wells, but the chlorine, the index of previous pollution, has greatly increased since the works were put in, due evidently to drawing water from a populated area from which it was not drawn in the beginning.

There are cases where it can be foretold that the water will

TABLE SHOWING AVERAGE QUANTITY OF IRON FOUND IN CERTAIN GROUND WATER SOURCES IN MASSACHUSETTS. TAKEN FROM THE REPORTS OF THE MASSACHUSETTS STATE BOARD OF HEALTH.

PARTS IN 100 000.

Source of Supply.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	1906.	1907.	1908.
Attleboro well	....	.0068	.0043	.0019	.0025	.0024	.0043	.0028	.0046	.0068	.0047	.0069	.0120	.0120	.0062	.0107	.0048
Avon well	.0115	....	.0100	.0020	.0300	.0010	.0047	.0038	.0030	.0058	.0049	.0047	.0042	.0045	.0047	.0045	.0040
Ayer wells	....	.0000	.0163	.0013	.0030	.0000	.0077	.0022	.0050	.0083	.0073	.0112	.0122	.0063	.0087	.0104	.0208
Billerica wells	....	....	....	....	....	....	....	.0101	.0252	.0280	.0287	.0435	.0382	.0432	.0463	.0414	.0362
Brookline. Tap at low service pumping-station	....	....	.0035	.0022	.0018	.0012	.0032	.0022	.0068	.0070	.0084	.0165	.0230	.0215	.0218	.0287	.0208
Cohasset. Wells in Ellms Meadow	....	....	....	....	....	....	.0038	.0027	.0053	.0043	.0046	.0065	.0190	.0050	.0033	.0027	.0040
Easton well	....	.0100	.0025	.0040	.0010	.0000	.0018	.0020	.0025	.0047	.0054	.0055	.0080	.0090	.0142	.0087	.0080
Foxboro wells	....	....	.0010	.0000	.0000	.0000	.0028	.0017	.0040	.0052	.0040	.0095	.0132	.0160	.0067	.0073	.0025
Groton well	....	....	....	....	....	....	.0068	.0048	.0082	.0050	.0048	.0076	.0040	.0095	.0060	.0052	.0017
Hyde Park. Old wells	....	.0112	.0175	.0149	.0141	.0089	.0113	.0107	.0340	.0312*	.0158	.0393	.0501	.0684	.0859	.0720	.0769
Lowell. Boulevard wells	....	....	....	....	.0098	.0222	.0310	.0388	.0591	.0260	.0297	.0317	.0337	.0402	.0439	.0562	.0715
Manchester. Large well	....	.0096	.0010	.0040	.0027	.0017	.0023	.0020	.0055	.0064	.0087	.0081	.0077	.0070	.0115	.0108	.0108
Mansfield well	....	....	....	.0000	.0030	.0040	.0013	.0010	.0020	.0037	.0046	.0029	.0063	.0100	.0065	.0023	.0030
Marblehead. Well No. 2	....	....	....	....	....	....	....	.2972	.3333	.3274	.4900	.2911	.4920	.4380	.4675	.4633	.4771
Methuen wells	....	....	.0050	.0133	.0123	.0052	.0038	.0092	.0223	.0077	.0095	.0322	.0333	.0580	.0365	.0336	.0319
Middleboro well	....	.0070	.0237	.0187	.0288	.0227	.0408	.0329	.0489	.0487	.0841	.0922	.1372	.1170	.1126	.1209	.1349
Monson well	....	....	....	....	.0092	.0123	.0037	.0103	.0045	.0060	.0072	.0072	.0040	.0030	.0033	.0023	.0033
Needham. Well No. 1.	....	.0000	.0020	.0000	.0010	.0000	.0015	.0021	.0029	.0045	.0055	.0038	.0038	.0030	.0047	.0050	.0025
Newton. Tap at pumping-station	....	.0119	.0110	.0146	.0108	.0122	.0032	.0028	.0029	.0053	.0057	.0095	.0103	.0137	.0080	.0063	.0053
North Attleboro well	.0158	.0040	.0178	.0020	.0127	.0028	.0023	.0040	.0073	.0120	.0087	.0083	.0082	.0272	.0115	.0090	.0080
Provincetown wells	....	....	....	....	....	....	.2289	.4433	.3774	.3809	.4100	.4713	.6837	.6930	.6787	.9750	.7900
Reading filter gallery	....	.1251	.2642	.2277	.2696	.2644	.2254	.1721	.2497	.2068	.1367	.1715	.2214	.2286	.2560	.2082	.2525
Walpole wells	....	....	....	....	.0015	.0023	.0037	.0020	.0140	.0051	.0057	.0102	.0037	.0032	.0068	.0077	.0036
Waltham well and filter gallery	.0034	.0020	.0044	.0082	.0137	.0108	.0162	.0082	.0086	.0182	.0257	.0305	.0352	.0437	.0439	.0744	.0290*
Ware well	....	.0035	.0010	.0020	.0010	.0045	.0014	.0010	.0042	.0067	.0047	.0032	.0045	.0070	.0090	.0068	.0032
Webster well	....	....	.0032	.0043	.0022	.0030	.0021	.0010	.0036	.0067	.0050	.0116	.0127	....	.0160	.0106	.0092
Wellesley tubular wells	....	....	....	....	....	....	.0068	.0022	.0068	.0045	.0100	.0076	.0107	.0055	.0072	.0059	.0053
Weston well	....	....	....	....	.0019	.0009	.0028	.0078	.0063	.0064	.0080	.0083	.0090	.0057	.0100	.0076	.0062
Winchendon well	....	....	....	....	....	.0047	.0115	.0113	.0112	.0058	.0115	.0156	.0447	.0620	.0627	.0660	.0932
Woburn filter gallery	....	.0004	.0021	.0023	.0011	.0012	.0015	.0015	.0032	.0045	.0048	.0052	.0052	.0038	.0035	.0028	.0032

* Draft from this source reduced by introduction of additional source of supply.

contain iron, and in other cases samples drawn from the test wells with a hand pump will show iron. There are also cases where it is reasonably certain that the water will not contain iron, but the only safe way, before installing a new supply, is to conduct a pumping test, drawing water from the ground at as great a rate as it is likely to be drawn after the works are constructed, and making frequent chemical examinations of the water. Of course the deterioration may be so slow that it cannot be foretold by a test of any reasonable duration, but in that case the deterioration after the works are put in is likely to be so slow that it will be safe to construct the works.

Pumping tests have been insisted upon by the State Board of Health of Massachusetts for many years, and in most of the new supplies, except for the very small ones, which have been introduced in this state for the past ten or twelve years such tests have been made. While in the majority of cases, after the source has been carefully selected, the pumping test has been satisfactory, and it has seemed as though the expense of the test might have been saved, in the few cases in which it has proven unsatisfactory it has been of enough value to more than warrant the expense of all of the other tests which have been made. In his own practice the writer has seen the results of fifteen pumping tests during the past three years, and in four of these the tests have shown unsatisfactory results. It should be said, however, that in each of these four cases the conditions were such that the results were not unexpected, but the test was carried on in the hope that the surface indications might be unreliable.

A pumping test consists in drawing water continuously from the ground at a rate at least as great as it will be drawn after the works have been constructed and are in general use. During the test careful measurements should be made of the quantity of water pumped, generally by means of a weir, and at the same time measurements of the height of water in the ground should be frequently made by means of open test wells located at different places within and around the area from which water is being drawn.

The length of time during which the test should be continued depends entirely upon the results obtained during the test. If

the general level of the water in the ground continues to go down with considerable rapidity, indicating that the water stored in the ground is still being drawn upon, the test should be continued. If, however, the level of the water in the ground becomes practically stationary, and the analyses indicate that there is absolutely no sign of deterioration in the quality of water, a test of one or two weeks may be sufficient. In some cases it has been found necessary to continue the test for periods of many weeks. After the pumps are stopped, frequent readings should be made of the height of water in the test wells to show the recovery of the water level, as without this information the test is likely to be of little value as an indication of the quantity of water available.

The results of the test will require careful interpretation, but when interpreted intelligently a very accurate prediction can be made, both of the quantity and of the quality of the water to be obtained from the source. So far as the writer knows, the results of a properly conducted pumping test have never proved unreliable.

From what has already been said, it is plain that the surface indications do not furnish absolutely trustworthy evidence of what may be found beneath the surface. The surface indications, however, are of sufficient value to warrant careful study before any test wells are driven, and the wells should not be located at random, as is sometimes done.

The sources of the water in shallow wells, such as we are considering, are, the rainfall upon the ground in the vicinity of the well, and water which may percolate toward the source from some neighboring surface water. The very best water generally is that which enters the ground directly from rainfall, since this is more likely to be unpolluted in the beginning and to be less subject to deterioration with increased draft from the source. The amount of water entering the ground depends upon the contour of the surface and the character of the soil. The water falling on steep slopes runs away very quickly and less enters the ground than upon comparatively flat land.

If the soil near the surface is compact and impervious, very little water can enter the soil. The most favorable condition, therefore, for obtaining water from the ground is a flat area of

sandy or gravelly land. When this condition is found, there is usually some place in the vicinity where good wells can be developed, although in some cases even these indications fail.

Ground water, in general, flows in the direction of the surface slopes, although this is not by any means always the case. In general, however, the best place to obtain the ground water is likely to be in some valley, not only because the ground water from the surrounding territory is likely to seek this low point for an outlet, but because it will also be found nearer the surface. Wet land, except when at about the level of the water in a neighboring stream or pond, indicates an impervious stratum, which keeps the water near the surface, and is not a favorable indication. It is usual to find in every town some old resident who will volunteer to assist in locating a well, and will lead the way to some spot which is never dry even in the driest season, which, in his mind, indicates an unfailing supply of water, whereas it really indicates only some stratum of clay or other tight soil through which water passes with difficulty and from which water cannot be obtained by means of wells.

There are times, however, when science fails and the old resident wins. The best ground water supply which the writer has ever seen was found by the superintendent of water works, who was making tests under his direction. He reported over the telephone very unsatisfactory results in the places selected, and wished to try one well near a spring on the farm where he was born. This the writer consented to, without having seen the location, feeling certain that the result would be as usual in such cases, — clay bottom bringing the spring to the surface, — but instead of that, one of the finest water supplies in New England was the result.

Swampy areas, or areas containing a considerable deposit of peaty matter, which is wet much of the time, should be regarded with very great suspicion. If wells are located sufficiently near to them, they almost invariably affect the quality of the water, unless there is an impervious stratum beneath the swamp which keeps this water from entering the wells.

When, as is usual, the ground water source is located in a valley near a stream or pond, a considerable proportion of the water is obtained from the surface source, this proportion depending on

many things, but chiefly upon the rate at which the water is drawn. Water obtained by infiltration from a surface source is satisfactory if conditions are such that it is well purified in its passage through the ground, that is, if the organic matter is completely changed over to inorganic. In many of the satisfactory ground water sources the greater portion of the water is obtained in this way. Such water may have some of the color of the surface source, and the temperature may be somewhat higher than that of a ground water not affected by the surface source, but there is no iron, and the water is bacterially pure.

The bottoms of many of our streams and ponds are covered with a deposit of material which is almost impervious to water, and it is probably due to this fact that the quality of the water obtained from wells located near surface sources is as good as it is.

In the case of Waltham, where the collecting works were located very close to the bank of the Charles River, it was found that wells on the opposite side of the river were affected by the draft of water from the collecting works, indicating that the bottom of the river was comparatively tight. There is, however, in this case, as in practically all such cases, a certain amount of infiltration from the river, very slow, and over a very large area, but sufficient to cause a material increase in the iron in the water.

It is frequently claimed, where works are located near a stream, that all of the water comes from the land side and that none is coming from the river, but such a condition requires an absolutely impervious stratum between the river and the wells, and those who have had occasion to excavate in the immediate vicinity of streams know that there is under all conditions considerable seepage from the stream, even in the small area occupied by a trench. When the level of the water in the ground is lower than that of the water in the river for a stretch of many thousand feet, as it is in many cases, it is impossible to believe that the ground is not fed to some extent by infiltration from the river.

In some of the supplies from wells and filter galleries the water is obtained almost entirely from adjacent surface sources, and when the conditions are favorable, such water is thoroughly purified and almost equal to the best ground water supply.

In some of the recent cases an attempt has been made, which has

proved quite successful, to increase the yield of the ground water sources by application of water to the surface of the ground in the vicinity of the wells. At Newburyport, the water from a stream some distance away is pumped on the gravelly soil above the wells and springs from which the supply is drawn. The water of the stream is of very poor quality, containing an enormous quantity of organic matter during the summer months, but although some of the water is lost, the quality of the filtered water is excellent and the results on the whole have been satisfactory.

A somewhat similar case is at Dover, N. H., where water is obtained from several wells and springs. The water of certain wells is of excellent quality, while that of others contains so much iron that it cannot be used for domestic purposes. In an emergency a rough filter was hastily constructed in the sand in the vicinity of the wells, which gives good water, and the water containing iron was thoroughly aërated and pumped to this filter, from which it found its way through the soil into the wells which contain good water.

It was the writer's intention in preparing this paper to have given some details in regard to the construction of works for collecting ground waters, together with costs and other data, but this must be omitted for the present. It may be said, however, that the cost of the preliminary investigations for a ground water supply is likely to be greatly in excess of the cost of the investigations necessary in connection with the development of a surface source, but the cost of construction may be much less. In one recent case a town, about ready to begin work in the development of a surface source at a cost of $300 000, found that an ample supply of much better water could be obtained from the ground at a total expense of $50 000. But whatever the cost, the superior quality of the water, and, above all, the safety in its use, should cause the ground water sources to be thoroughly investigated before determining upon a supply from a surface source, which is certain to be inferior.

DISCUSSION.

THE PRESIDENT. Gentlemen, you have heard the paper, which, it is proper for me to say, and I think you will all agree with me, is one of the most interesting papers which has been read before this Association for a number of years. I hope there will be a full and general discussion of the subject.

MR. LEWIS D. THORPE.* We constructed a new system in Newburyport last year, the supply being taken from a small tidal river. A dam was constructed, with its crest at an elevation sufficiently high to exclude the salt water, across the stream at a point near its outlet, and from this stream the water was pumped a distance of about two miles and discharged on to natural sand filters. These filters are constructed in a small ravine which is located a short distance away from the main pumping station. In preparing the beds, all the loam and subsoil were removed to the surface of the sand and the sand leveled, the loam and subsoil being used for the embankments. Two open beds were constructed, one having an area of about 30 000 square feet and the other 15 000 square feet. No underdrains were used. The water passes through the filters at a slow rate and is collected in trenches in which vitrified pipe surrounded by screened gravel is laid, and is conducted into a small reservoir located about 150 feet distant and 45 feet lower than the surface of the beds. This reservoir is uncovered, and has a capacity of about 600 000 gallons. From the reservoir the water flows by gravity to the main pumping station, from which it is pumped directly into the city mains. In addition to the open filters, about 5 000 feet of sub-surface filters were constructed for use during the winter months. These filters are of 8-inch vitrified pipe, laid with open joints and embedded in screened gravel. They are laid in four lines, extending around the slopes of the ravine just outside of the open filters, and are about 4 feet below the natural surface. It is not proposed to use the subsoil filters when it is possible to use the open beds. The system has been in operation about one and one-half years, during which time we have pumped about 400 000 gallons per day from this source. From the analysis made by the State Board of Health the

* Civil and Hydraulic Engineer, Boston, Mass.

results have been satisfactory. The water in the river is full of vegetable growth and highly colored, and is unfit for domestic use without filtration. The open beds were constructed for use during the warm weather, but last winter they were used throughout the freezing months with good results and with very little trouble. The depth of sand in the ravine and filters is from 30 to 40 feet, under which is a layer of hardpan, the general slope of which is in the direction of the collecting reservoir. Of the total amount of water pumped on to the beds, about 70 per cent. has been collected in the reservoir during the past eighteen months; the balance I am unable to satisfactorily account for.

MR. A. O. DOANE.* Some years ago, when Newton was putting in a number of wells along the Charles River, I made a large number of temperature measurements of the flow from 2½-inch pipe wells, driven about 20 feet apart to a depth of 40 or 50 feet, and within 100 feet of the river. I found that the temperature in nine tenths of the wells was the ordinary temperature of ground water, about 48 to 50 degrees. This was in the summer, when the temperature of the water in the river was very much higher than that, perhaps at times around 80 degrees in very hot weather. Occasionally one of the wells would be 15, or, in some cases, 20 degrees higher than the wells on either side. This seemed to show that that particular well connected with some stratum which had a much more direct connection to the river than the others, and the low temperature of the other wells showed that the water was coming mostly through the ground for a considerable distance.

We also found that the water in wells driven in the river bed would stand at a higher elevation than the surface of the river. Our observations showed the same condition that Mr. Johnson spoke about as occurring in Waltham, namely, that the wells on one side of the river were affected by the draft on the wells on the other side.

MR. GEORGE E. WINSLOW.† Mr. Johnson speaks of the Waltham wells in a number of places, and it might be inferred from what he says that a great deal of this supply comes from the river. The basin, formerly called the filter gallery, is about 50 or 75 feet from

* Division Engineer, Metropolitan Water Works, Boston, Mass.
† Waltham, Mass.

the river. When we increased our supply, by building a well some 18 feet deep in this basin, I tried a number of experiments to find out how much water we took from the river.

Before digging this well we made tests with a 5-inch pipe driven about 83 feet deep between the basin and the river. This well would yield with hard pumping 175 gallons of water a minute. As an experiment to see whether this well would add to our supply, I pumped the water into the river for twenty-four hours, noting the level in the basin and the amount of water pumped, the water being kept at the same level in the basin in pumping to our reservoir. I found that in pumping it into the river I decreased the amount of water from its normal condition. I then turned the flow into the basin, and found that I increased the supply. This experiment showed that we could get more water by driving wells near the basin. We concluded, therefore, to increase our supply by putting in a well inside the basin.

The question then arose as to how much water we would get from the river and how detrimental it would be to draw so much water. So I suggested the idea of putting a driven well over on an island across the river, the well being about 1 000 feet from the basin. I was laughed at a good deal, however, for having an idea that I could draw water from that island into our well. While building the new well I had readings taken on the island three times a day, and I found that we lowered the water there to a maximum depth of 2.8 feet below the water in the river. When we were not pumping, the water came back to its normal height, which was 0.2 of a foot above the water in the river, making a total of 3 feet that we lowered the water in the well 1 000 feet from the basin and across the river. So we were satisfied that we did draw the water from there.

Furthermore, Mr. Noyes, formerly city engineer of Newton, told me that we went a good deal further than that. He said, " You lower the water from six inches to a foot in our Auburndale wells when you are drawing your well down to the lower level and holding it there." Those wells were two miles from the basin.

Experiments were tried to find out how much water came from the river by making tests of the temperature of the water in the basin and in the river. When the water was drawn down and the

men were at work shoveling the earth out, I got temperatures of 52, 53, and 54 degrees, according to where I put my thermometer in the basin. There was a slight difference there, very little of it being up to 54 degrees. When it went from the pumps — there were seven centrifugal pumps working, three of them 8-inch and four of them 6-inch pumps — it ran through a weir to the river; at this weir the temperature was 54 degrees. Of course I don't say that that was the temperature of the water normally; it was the temperature of the mixed water as it came from the basin, increased perhaps a little by friction in its passage through the pipes and the pumps. The water in the river at that time stood at 72 degrees, and we got a rise of 2 degrees from the different causes.

Now I don't know, and I don't know of anybody who can tell me, how much of that water came in from the river under the conditions I have named. I know that it would take a lot of it to bring it up the last 2 degrees, but a very little to bring it up the first 2 degrees, so I am satisfied that there was but a very small amount of water came in from Charles River.

MR. JOHN H. FLYNN.* I would like to ask Mr. Johnson if he has had any experience with the witch hazel stick, and if so, what his experience has been and what he thinks of the man who manipulated the stick?

MR. JOHNSON. I have seen many successful wells located by the witch hazel stick, but the stick was always handled by a pretty clever sort of a man, who knew where to look for water.

I had thought that the witch hazel stick had gone out of business, but I ran across a case last summer where a well had been located in that way, and the owner, although rather skeptical about the witch hazel, considered the results marvelous. The owner described how the man wandered around aimlessly with the stick, and finally came to the bottom of the valley, where he paused, went back and forth, and seemed to have found something. Finally the stick went over, and the man dug his heel into the ground and announced that there was water there. This he did three times, locating three different springs within a radius of five or ten feet. When the well was dug, there were the three streams of water entering it as prophesied, much to the amaze-

* Boston, Mass.

ment of the owner. The springs dried up in summer, however, so that another well had to be dug in a more favorable location, but the witch hazel stick had not failed.

I would like to add something to what Mr. Thorpe has said with reference to Newburyport. The impossibility of telling from surface indications what there is beneath the surface was well illustrated there. The area on which the water is pumped is a gravelly hillside sloping rapidly toward the Merrimac River, the top of the slope being at least 75 to 100 feet above the water of the river. The soil appears to be sand and gravel, and the only visible outlet for the water is a ravine with steep sides, which cuts into the bottom of the hill. In this ravine there is a natural spring, which has been one of the sources of water supply for many years. To make certain, however, that the water would not go in some other direction when it was put on this gravel slope, test wells were driven all over the slope. It was found that, even on the steep slope leading toward the river, some of the ground water evidently went in a direction opposite to the slope and away from the river.

In the ravine near the foot of the slope and below the natural spring, it was proposed to construct a cut-off dam to prevent the escape of any water through the ground, and test wells were driven every few feet across the ravine in order to determine the necessary depth of the cut-off dam. These test wells indicated that the ledge followed the contour of the surface quite closely, so it was proposed to carry the cut-off dam down to the solid ledge. When the cut-off wall was built, however, it was found that what appeared from the test wells to be ledge was simply a mass of loose bowlders, every one of the test wells which had been driven to find the ledge having struck on one of these stones. This experience simply shows the unreliability of surface indications, and that at times even test wells may give a wrong idea as to the formation beneath the surface.

MR. HAROLD K. BARROWS.* I was especially interested in what Mr. Johnson said regarding the testing of wells, and his opinion that a ground water supply should be tested by pumping, if practicable, up to or beyond the amount of the probable future con-

* Hydraulic and Sanitary Engineer, Boston, Mass.

sumption. I think this is excellent advice. In case it is not practicable to carry the pumping test to this extent, it is of interest to know something about the manner of predicting the probable future yield.

Prof. Charles S. Schlichter, of the United States Geological Survey, has investigated very fully along those lines, more especially in the West, and has developed some complicated formulæ (to which, I presume, Mr. Johnson referred) applicable in studying the direction of flow and amount of ground water available, which are not of much practical service to the engineer. He has, however, gone further and evolved some practical results. [See Water Supply Paper 140, United States Geological Survey, page 86 *et seq.*] He defines the *specific capacity* of a well as the amount of water furnished under a unit lowering of the surface of the water in the well by pumping. Thus if the water in a well is lowered 2 feet below the natural level by continuously pumping from it, at a rate of 20 gallons a minute, the same well may be expected to yield approximately 40 gallons a minute if the water is lowered 4 feet below the natural level. He further states that for shallow wells the yield will not increase in this direct ratio, but will be considerably less on account of the decrease in percolating surface due to the lowering of the water plane in the neighborhood of the well.

It is likely that Professor Schlichter's conclusions are not generally applicable to our New England conditions, where there are frequently many changes in strata and material in comparatively short distances. There is a dearth, however, of reliable data from pumping tests of wells under various conditions, and if such information were at hand in systematic and comparable form, analysis might enable some conclusions to be drawn that would be of service in predicting the probable yield of a well from a pumping test with a delivery less than the future amount required.

Another subject of interest in connection with ground water supplies is that of large wells. We do not often hear of wells of large diameter being built, the ordinary method being to drive a number of wells of comparatively small diameter. Usually the latter is most economical, especially in first cost. Now, are there not sometimes locations in which a large well may in the long run better suffice to provide a water supply? What I have in mind is

a case where the material is a rather fine sand, which does not yield the water readily, and where the reservoir capacity of a large well would be a distinct advantage; that is, it would be filling while the pumps were not in operation. I should be interested to have this subject discussed at greater length, especially in regard to the cost of such wells and methods used in their construction at different locations.

MR. WILLIAM F. SULLIVAN.* Mr. President, I was interested in the question and remarks of Mr. Flynn with regard to the so-called witch hazel experts or water smellers. I was on a job where they employed a marvel of a man, who claimed to possess powers and wisdom beyond the ordinary mortal when it came to locating ground water. A cruising party, including the fellow with the divining rod, started along and parallel to a river bank on a path leading across a small footbridge covered with sand and dirt and fringed on both sides with bushes. Under the bridge flowed a small, swift-running brook. The "wonder" had a stick in his hand, feeling happy and looking wise. As he crossed the bridge the stick did not show any agitation or indication of water. We called his attention to the lack of sensitiveness of the rod. He appeared embarrassed, but explained it away by saying that surface water had no effect on the rod or the electricity in his body. We continued further along and led him directly over a spot where a few days previously we had driven and washed down a test well 90 feet deep, which yielded 50 gallons per minute. The pipe had been pulled up and a twig thrown over the hole in the ground. Again the divining rod failed to detect, this time, ground water. After being told that there was an abundant supply there, he tried again, and he reckoned that he had not been holding the wand just right. About this time he was somewhat of a discredited prophet.

From the man's talk and explanations, I came to the conclusion that this particular wonder-worker was only a poor human being like-ourselves, not even possessing the knowledge we had, as we had samples of the strata to guide us on our hunt for water. I believe that he worked on the assumption that water underlaid the surface of the ground in large or small quantities almost everywhere, particularly where the surface indications showed large

* Engineer and Superintendent, Pennichuck Water Works, Nashua, N. H.

deposits of sand and gravel; and that, in case of rock formation, the drill would sooner or later strike a seam below the water table; that this fissure would ramify off in different directions and permit more or less water to percolate into the well. Experience has proven this assumption correct, as there is water in the different kinds of material, such as clay, sand, and gravel, below the water table, the question of quantity depending on the porosity of the material if backed up by sufficient drainage area or an adjacent surface supply.

Mr. Johnson speaks about test wells and subterranean streams. I have always believed that these so-called subterranean streams were nothing more or less than water percolating through coarse material to a lower level, and that certain reports which give the impression that you could float a log through an underground channel were erroneous and misleading. The subterranean basin, however, is present wherever you are able to get water from a well. The extent and capacity of a basin depends on the extent of the deposit of sand, gravel, or other water-bearing materials and the percentage of voids.

My experience has been that test wells show the extent of a subterranean basin and how much it is affected by pumping, and its recuperative powers. Test wells also show that the water feeds into the basin from different directions and at different rates of flow, and that the frictional slope is not the same in all directions from the well system, showing in the average well plant that there is a freer passage in some directions than in others, and that subterranean basins do not draw down uniformly around a gang well system.

In regard to temperatures, my experience agrees with Mr. Johnson's. In some well supplies, the temperature in the spring is between 48 and 50 degrees as a minimum, and, as the season advances to the summer months, the temperature increases to about 67 degrees, while the temperature of the surface water is about 75 degrees. When the temperature of the surface water drops in the fall, the ground water continues warm until about November.

I would like to ask Mr. Johnson if he can give the reason why, when a gang of wells are being pumped and the temperature of the water from the gang wells is 65 degrees, an individual test well

located within the zone of the draft, say, within ten feet of the well system, has an almost uniform temperature throughout the year?

Speaking of imperfect filtration and the deterioration of water from wells, I would like to ask Mr. Johnson if he knows, in the case of a well plant located near a stream or pond, the analysis of the well water indicating imperfect filtration, whether or not all of the filtering material that lies between the wells and the surface water is affected? In other words, has the material as a whole become imperfect filtering material, or is it just a small portion around the open end or around the strainer of a well? To put the question in another way, if you should move such wells five or ten feet and keep the same location of the suctions or well lines, would the water be as good as was obtained when the plant was first installed?

MR. FLYNN. Mr. President, I am a little interested in this witch hazel matter, for I claim to have a certain gift in that direction myself. In this city we have four wells which I located by a stick. We use them instead of ice for lowering the temperature of water for drinking purposes. In every case I found water where the stick indicated that there was water, and I found it at the temperature of 50 degrees. Within two months I have located a well for the tuberculosis camp in West Roxbury. They wanted water out there, and we didn't have any water within quite a distance of them, and it would cost something like $8 000 to have the water main extended to their camp. I didn't use the witch hazel stick in that case. I went over to a house across the street from where the camp is and I cut a twig off an apple tree, and I found it would work just as well as the witch hazel. It all depends on the man behind it. Now, there is something in this. Nobody has ever explained what it is, whether it is the magnetism in the man or in the stick, but of course I claim it is in the man. I will tell you how it has worked with me. In two or three cases where there were strong indications of water, and where I got water very close to the surface of the ground, and an abundance of it, I held the stick in my hand and did my utmost to stop the stick from going down; I tried to keep it from going down, but it went down in spite of me, turning and leaving the bark in my hands.

MR. JOHN C. WHITNEY.* I should like to ask Mr. Johnson why the inflow of surface waters into a ground water supply located near a stream should largely increase the amount of iron in that ground water?

MR. JOHNSON. First, Mr. President, in answer to Mr. Barrows' question in regard to the use of large dug wells, I would say that I think there are many places where a large well is much better than driven wells. There are other places where a large well would be better if it were not for the greater cost. In rather fine material, or where for any reason the flow through the ground is somewhat slow, it is a great advantage to have a large quantity of water stored in the well to supply the pumps. At the end of the pumping the well may be drawn to a low level, but it will recover before the pumps are started again. There are other places where the water-bearing stratum is so shallow or so near the surface that driven wells are not practicable, for when you draw water from the driven well the water level is lowered a good many feet in and immediately around the well, the distance depending upon the character of the material in which the well is driven and the rate at which the water is drawn. If a sufficient depth of water cannot be secured, it is better to dig a large well. The advantages of the driven wells are, first, their small cost in comparison with the cost of a large well; and, second, the comparative ease with which the driven well system can be extended to draw water from a large area.

In regard to foretelling the amount of water which can be obtained from the ground by pumping at a slow rate, I would say that I have never been able to do it. Undoubtedly, if the porous material from which the water is drawn were of uniform quality, and extended for a long distance in all directions from the well, it would be perfectly possible to make such computations. In practically every case of which I have any knowledge in this part of the country, the conditions as to the character of the soil and the depth and direction of the different strata are so complicated that it would be an absolute waste of time to attempt any such calculation. In some cases with which I am familiar the water is drawn from a pocket of porous material surrounded by impervious mate-

* Water Commissioner, Newton, Mass.

rial, and the volume of water which could be obtained could not be increased by lowering the level of the water in or around the wells. In other cases the wells are situated near or in a large deposit of sandy soil, and by lowering the level of the water in the wells a few feet a great increase is made in the area affected by the wells and in the quantity of water flowing toward them. Some time ago I made the prediction, based on information obtained from studying the quantities of water previously drawn and the corresponding changes in the level of the water, that a certain well would yield about 250 000 gallons per day in a very dry season. During the last two summers, which have been very dry ones, water has been pumped from that well at the rate of about a million gallons per day, and it became my unpleasant duty to explain this discrepancy in a town meeting a short time ago.

Mr. Sullivan asks why the temperature of a test well somewhat off the line of wells from which water was being pumped should be low and the temperature of the gang wells high. This probably means that the water coming from different directions toward the wells has different temperatures, and the test well which he speaks of as having a low temperature was in the vein which came from a district furnishing cold water. If the gang of wells was beside a surface source, I would say that much of the water came from the surface source by direct or indirect filtration, but the test well was in a vein of water which was either coming from the land side and not from the surface source, or was coming more slowly from that source.

I do not think moving the wells affected by iron further away from a stream would do much good unless they were moved a considerable distance. The appearance of iron is not due to the deterioration of the filtering material, but rather to the change in the rate of filtration or the draining of the water through some new channel. It is just the same as if Mr. Collins increased the rate of filtration of the Merrimac River water at Lawrence. He would get poor results. If the rate were sufficiently increased, he would undoubtedly get iron.

Where wells are located a sufficient distance from a surface source so that water is drawn from that source over a large area, as

in the case of a location near a stream, where the water may enter the ground for several thousand feet above and below the wells, the water is not likely to deteriorate very rapidly.

Mr. Whitney's question as to the reason why the entrance of surface water into a ground water supply located near a stream should increase the amount of iron in the ground water is a somewhat difficult one for me to answer as it involves considerable chemistry. In a general way, it means imperfect filtration of the water. Exactly the same result is seen when sewage is applied to sand filter beds at too rapid a rate or in too large doses. One of the first indications of such abuse of a sewage filter is the presence of iron in the effluent. No water which contains oxygen or air, contains iron, since the oxygen will unite with the iron, forming an insoluble oxide which is left behind in the soil and which sometimes gives the soil the appearance of iron rust. Perfect filtration means that there is always sufficient oxygen to burn up the organic matter. Now when you draw water from a pond containing a lot of organic matter through a bed of mud on the bottom, there is not sufficient air in the water to provide the requisite oxygen for burning up the organic matter, and it is necessary that there should be an opportunity for oxygen to get at the water as it is drawn through the soil before it enters the well, or there will be iron in the water. This is a simple explanation, but I believe it does not tell the whole story chemically. The further away the wells are located from the source of the water containing organic matter, the less chance there is of getting iron in the water, because it gives so much more opportunity for the oxygen, which is normally present in all sandy soil, to get at the water.

Mr. Robert S. Weston.* The chemistry of iron in ground waters is rather a complicated subject, and I know of no simple statement of the conditions which would be better than Mr. Johnson's. Those waters which contain the least iron are those which have had the most oxygen admitted to them during their history, either before or after they come to the surface of the ground. The decomposition of the organic matter in the ground uses up the oxygen and produces gases which dissolve the iron. Iron-containing waters, when exposed to the air, rapidly absorb

* Consulting Engineer, Boston, Mass.

oxygen, which, in the course of time, causes the iron to rust, that is, to become insoluble and precipitate. This precipitation is helped or hindered by various factors, a description of which would require too much time.

There is one point in connection with Mr. Johnson's paper which I would like to emphasize, and that is the necessity of conducting pumping tests, not only through a dry, but through a fairly wet, season, especially when wells are located near meadows. In these cases the water coming from the highest side is apt to be very good, while that coming from the meadows may contain iron in a form difficult to remove, especially after a sudden shower has fallen upon this meadow or it has become flooded by an overflow. In these cases the water seeps down through the peaty matter in the meadow, dissolves out the iron, and contaminates the water. This contamination might not reveal itself if the pumping test were conducted through a dry season only. It would be well in all cases to continue the pumping tests well into the wet season. The more information one can have regarding the quality of the water in addition to a knowledge regarding the quantity of the water, the better.

I am very glad that Mr. Johnson has emphasized the fact that one man can see underground about as far as another, and that in New England the water-bearing sand and gravel exist in pockets and not in layers, as they do in other countries and in other parts of this country.

Regarding the infiltration of pollution from surface sources into filter galleries and wells located alongside of them, there is some difference of opinion. The fact was denied a few years ago by many advocates of ground water, but recent experiments have shown that such infiltration does occur, and the amount is a function of the differences in level of the ground and surface water, the thicknesses and sizes of material through which the water has to pass, and the rate of pumping. In Dresden slight pollutions of the ground water supply have followed floods of the Elbe. In northern Germany wells near drainage canals have proved bad, while those some distance away have furnished good water.

MR. HARRY W. CLARK.* Nearly all soils and gravels contain

* Chemist, Massachusetts State Board of Health, Boston, Mass.

iron in combination with silica and other mineral substances, and if a water containing organic matter enters the ground from a pond or river with not sufficient oxygen present to oxidize this organic matter, it takes for this oxidation oxygen from these basic oxides in the soil, reducing them to a soluble form. When the water is exposed to the air, ferric hydrate if formed and precipitates. The presence of iron is not, I believe, a question of distance; it is simply due to the fact that the water does not start with enough dissolved oxygen to oxidize the organic matter present.

MR. M. N. BAKER.* I was particularly interested in Mr. Johnson's statement relating to the percentage increase in ground water supplies from 1879 to 1909 in the state of Massachusetts. This has occurred to me as in part explaining it: In 1879 there were in Massachusetts, as in the other states of the Union, a comparatively small number of water works, and they were divided into two classes, broadly speaking. One was for the larger cities, that might not so readily draw upon ground water for their supply; and the other class of water supplies was for the smaller places, many of which had originated early, when there was an opportunity to bring in a small gravity supply from some near-by source. Pumping was not involved.

In the course of time a large number of water works have been built, and in the last few years the new works have been almost wholly in the smaller places. For the smaller places it is very much more feasible to develop a ground water supply than it is for the larger places. It seems to me that that might in part account for this percentage change.

Unquestionably the arguments which have accumulated in the last few years in favor of ground water supplies as against surface supplies, on the point of superior quality, have had a great deal to do with the percentage increase in the ground water supplies, and deservedly so. I think it is worth noting, perhaps, that there has been the same general increase in the percentage of ground water supplies in other parts of the world, and that it has been noticeable in Germany. There, if I am correctly informed, there has been in the last fifteen or twenty years a very remarkable turning to ground water as a source of supply. This has even had

* Editor, *Engineering News*, New York.

governmental sanction, if not official pressure, including even the personal influence of the emperor of Germany.

There is an attitude of the Germans in regard to water supply, and particularly in regard to stream pollution and sewage purification, which I think we ought continually to bear in mind in this country. I noticed when I was in Germany, and it has come to my attention from time to time since, a letting up in the attempts at a high degree of sewage purification, and an accentuation and a greater insistence upon the purification of all water supplies. I think the movement for ground water supplies in Massachusetts and elsewhere is largely a recognition of the fact, as is so well brought out in the paper, that we cannot depend upon surface water supplies in point of purity unless we resort to purification. Now the more we follow out that line, the more, I think, we will see modifications in the attitude of the people of the country towards sewage purification. We have got to have sewage purification in order to protect many of our streams, but we must get away from the popular idea that we can purify sewage so as to make it a safe drinking water.

There is a very extensive German literature on the science of ground water flows and on the yields of wells. Underground water flows have also been studied by the United States Geological Survey, and while, as it has been very well put, those studies have far greater significance elsewhere than in New England, yet they have significance. Those who wish to be guided by all that is available on the subject should have recourse to the German literature and also to the quite voluminous literature that has been published by the Water Resources Branch of the United States Geological Survey.

MR. SULLIVAN. There is one other matter connected with well supplies that has always impressed me, and that is the cost of maintenance, the cost per million gallons pumped, and the yearly cost of a ground water plant as compared with the cost of a filter plant, the cost, so far as I know, being much in favor of a well plant.

Prior to the time the State Board of Health took up the matter of water purification, a town or city installing a water supply could go to almost any stream or pond and take its supply and

take it raw. Now that has all been changed. It is almost compulsory, and rightly so, that supplies should be pure and wholesome, and the cost of getting a pure supply, in many cases going miles for it, where once it could be obtained near at hand, and the enormous costs of pipe lines, storage areas, and dams for surface supplies, make such works prohibitive in many instances. First-class and up-to-date filters are expensive, and where unpolluted surface supplies are not available, or where a suitable well supply cannot be found, filters are necessary.

On the other hand, where a well supply can be found, it is usually adjacent to a city or town, and can be installed at a low cost. Well supplies have solved a difficult problem for many towns, cities, and industrial concerns.

In regard to the comparative cost of obtaining a water supply from surface sources, filters, or wells, I would like to ask Mr. Johnson if he has any comparative figures showing the cost of installation per million gallons. Also, whether he has any data showing the comparative cost of maintenance of well plants, as against the cost of filter plants, say, for about a pumpage of five million gallons per day.

MR. JOHNSON. I haven't any such figures. Of course, the difference is great because a well plant, as has been said, costs very little to maintain, much less, probably, than the cost of maintaining the mechanical parts of a filter plant. In addition, you have in a filter plant the cost of removing and cleaning the sand and the cost of constant attendance.

MR. SULLIVAN. I would like to ask Mr. Johnson if a well plant is not less liable to accidental pollution than a filter plant?

MR. JOHNSON. Unquestionably. It is hard to conceive of any serious accidental pollution of a ground water supply, while it is always possible in a filter plant by ignorant or careless operators to let impure water pass the filters.

MR. WESTON. Mr. President, Mr. Sullivan might be interested to know that the cost of a ground water supply with a plant for removing iron would be less than the cost of a surface water supply with sand filtration.

MR. M. F. COLLINS.* We have a good opportunity in Lawrence

* Superintendent Water Works, Lawrence, Mass.

to judge of the cost of operating a filter plant. On our open filter the cost of maintenance will run anywhere from $5 close to $6 per million gallons. On our new covered filters we have kept a pretty accurate account of the cost of operation, and we can operate them for a little less than $1.50 per million gallons. That shows clearly what a benefit there is in having a covered filter, where you eliminate ice formation in the winter. Another advantage is that you are able to enter it at any time for cleaning, whereas with the open filter you have to depend a great deal on the weather conditions.

We have had a little experience up in Lawrence with driven wells. We spent somewhere in the neighborhood of $6 500 in experimenting with them. Mr. Johnson speaks about the superior knowledge of some of the oldest inhabitants as to just where water can be found. We have had a few of this type of citizens to contend with. One of them had a plant which he knew would give the city of Lawrence 10 000 000 gallons a day easily. We went up and tested his wells without favorable results, and he came down and complained that we didn't give them a fair test. He was on an elevation of some forty feet above the Merrimac River and had a spring from which he was selling water to the citizens of Lawrence. He claimed he was getting his water from an underground source which came from Vermont, flowed through southern New Hampshire, and thence down to his place. How he got that knowledge, I don't know; probably Mr. Johnson could tell. [Laughter]. The city government felt that we ought to give his spring another test, so we fortunately obtained the late Mr. Smith, a very good, reliable, honest man, to make tests for us. We went up there again and drove some three or four wells, and did succeed in one of them in getting about six gallons a minute. In the others we couldn't work the pump handle at all, it was so air-bound.

There was another gentleman who had a lot of land partly in Lawrence and partly in Methuen, where the two police officers lost their lives, who said that he had water enough in his plant to supply Lawrence for the next one hundred years. So, at the request of the city government, we sunk two wells, one about thirty-eight feet, and the other about forty feet deep. We pumped

for an hour and didn't get a gallon out of either one of them, so that gentleman's theory was knocked in the head.

When you are working on tests of this kind, it is astonishing how many people know just where water is to be found, and how much will be furnished. A German came down to the office one day and told us that he lived near a place called Sow Brook, pretty near the Methuen boundary line, and said that there was a fine flow of water there, sufficient for the city's need. He went before the water board and the members of the city government, and they requested us to go up and sink some wells. We went up and happened to have the city engineer with us. We saw the German and he told us he didn't know so much about it as his wife, but his wife knew there was plenty of water there. We went and saw her, and she showed us the water flowing, and said she had no doubt that it would supply the city of Lawrence easily. But there wasn't water enough to fill a 3-inch pipe, and when we told her how much we wanted, she admitted her ignorance on the subject.

Mr. George A. Stacy.* Mr. President, speaking of people who know where underground water supplies are, I recall to mind a little experience we had when we were looking for our additional supply. There was a good man, an old citizen of the town, who had quite an area of land near the city, and there was a spring on it. He was satisfied that it was a never-failing spring, such as we often hear about, and that it would be foolish to go to work and spend $200 000, and some said $1 000 000, for another supply when one was right there running to waste, and so high that part of it only would have to be pumped. Of course, we had very serious doubts in regard to it, knowing the condition of things, but he made so much talk that the members of the city government, not having had a chance to investigate such things as much as we have, were rather uneasy for fear we might make some mistake, and so we agreed to test the well.

We went up with a common 3-inch diaphragm pump, such as we use on the ditches, and put two men at work. We set up a little weir and we pumped one afternoon. We pumped this well down to within about two feet of the bottom and held it there

* Superintendent of Water Works, Marlboro, Mass.

with very little work all the afternoon. The old gentleman was quite elated. He was a man whom we all respected, and he believed just what he was talking about, that there was water enough there. In the morning the well was full again. Then he thought he had the real thing, sure. But we went up there and put in two pumps the next day, and in the middle of the afternoon the well would supply one pump part of the time only. The result was that after that day's work that well, or spring, didn't fill up again, I think, for about thirty-six hours, showing what the actual flow was. We went to all that trouble, knowing what the result would be, to demonstrate that this nice old gentleman was wrong in his idea and didn't know as much about water supplies as some other people who had made a longer study of the matter. We all run up against that sort of thing at times, and we have to cater to it to a certain extent in order to satisfy the people as to the true facts in the case.

REPORT OF THE COMMITTEE ON THE DEPTH OF LAYING WATER PIPE.

[*Read December 8, 1909.*]

NEW ENGLAND WATER WORKS ASSOCIATION:

Gentlemen, — Your committee on the depth of laying water pipe, appointed at the annual convention of 1908, begs to submit the following report.

Three hundred and twenty circulars of the form shown in the appendix have been sent out, to which ninety replies have been received. The information required by the circular was of two classes, the first comprehending general data in regard to local conditions and practice in laying water pipe, and the second covering the results of particular experiences in freezing.

Concisely it may be stated that the result of the investigation made by your committee is largely negative in character, — that is to say, it appears that freezing has not occurred at the depths generally adopted for laying water pipe. Whether these depths are excessive, however, cannot be predicated from the information at hand, because where freezing has occurred there has always been an obvious explanation, usually little or no velocity, and an analysis of these explanations and of the local conditions pertaining does not finally justify any general deduction as to necessary depths.

Considering the results of our investigation in greater detail, reference may be made to the appended tables which summarize the replies received to the questions of the circular. While these replies do not provide the information necessary for conclusions of much practical value, it is believed that there is sufficient information contained therein to make their publication worth while. There is little doubt that if a more general response to the circular had been obtained something of real value might have been worked out and it may be that the presentation of the data now collected will provide a basis for future work and stimulate further study of the problem.

Table 1 shows the replies to the questions asked in reference to local conditions and practice, and Table 2 gives the information obtained of actual cases of freezing. From these tabulations it is apparent, as already stated, that in general the depths now used are sufficient to prevent freezing, but it is less evident whether or not these depths could safely be reduced. Either it must be concluded that present standards express the results of a gradually developed experience and that the present depths are the least which would be safe, or else there is a possibility of lessening these depths without danger. This conclusion is indicated from the fact that with practical unanimity all replies state that the present depths are sufficient, and a considerable number suggest that lesser depths might safely be used. Whenever freezing has occurred it has been largely at night or where there was practically no current, and it is believed that where there is a velocity, say, in excess of one quarter of a foot per second, and particularly in the case of ground water supplies, depths somewhat less than those now used would generally be safe. In main feeders, and in those portions of the distribution system where there will be an assured circulation, the question of minimum depths should be given careful consideration. It is not in the mains but in the services that most of the trouble from freezing occurs, and in the services such trouble usually results from skimping by plumbers or contractors, resulting in the actual laying of the services at depths considerably less than the mains. There is a strong feeling apparent that services should be laid by the municipalities.

Twenty-eight of the places replying report the tapping of service connections on the top of the main, 39 on the side, 12 on the quarter, and 7 in various ways. Freezing of services generally starts at the house and backs out into the main, and it is believed that if services were tapped on the side of the main and then dropped to the depth required to meet local conditions, the lessening of the depth at which the main is laid to that justified by the velocity of the water in the main would not result in increased freezing of services.

In determining the depth of pipe, the character of the soil and of the surface of the ground are factors of some importance. In but very few places, however, from which replies were received is the nature of the soil taken into account in deciding as to the necessary

		Temperature. Degrees Fahr.			Location of City.			
	Mean Yearly Temperature.	Mean Temperature Coldest Month.	Extreme Minimum Temperature and Date of Occurrence.	Minimum Temperature at Source of Supply and Date of Observation.	Distance from Ocean. Miles.	Elevation above Sea Level.	Source of Supply. Surface or Ground Water.	
Maine								
1 Auburn		10			20	210	Both	
2 Bangor					40		S	
3 Brewer					40±	25±	S	
4 Rumford	41.5	16.1	−24		85	450 to 600	G	
New Hampshire								
5 Dover		−24			10		S and G	
6 Manchester		−10	−10		40	900	S	
7 Nashua	46.0 for 2 yrs.	10	−15 (Feb. 13)	−15	40	150	G	
Massachusetts								
8 Billerica	49	Temp. of water 50	43	43	20	111	G	P
9 Boston	51.5	26.8 (Feb.)	−2 (Feb.)		On ocean	18 to 250	S	
10 Brookline					4	10 to 365	G	
11 Cambridge							S	
12 Fitchburg	46			20	50	360 to 700	S	
13 Fall River					20	270 H. pt.	S	
14 Hyde Park					6	35 to 200	G	
15 Lowell	46.7 47.0	20, Air 38, Water			25	90	G	P
16 Lowell (Locks and Canals)							S	
17 New Bedford	48.5	18.6	Below zero, but not for long	−13 (Jan., '07)	Ocean	0 to 154	S	
18 Reading					10	100	G	
19 Sharon					18	250 to 530	G	
20 Springfield	51.6	7.7	−23 (Jan., '07)	−40 (Jan., '04)	100	73 to 200	S	
21 Stoughton							S	P
22 Westfield	52	20	−12 (Feb., '08)	−16 (Feb., '08)	100	150+	S	
23 Worcester					44	485	S	
Connecticut								
24 Bridgeport		+20	−7		Ocean	10 to 35	S	
25 New London	50				3	0 to 150	S	P
26 Norwich					15	0 to 230	S	
27 Rockville					150	500	S	P
28 Wallingford					12.5	50 to 180	S	
New York								
29 Canandaigua	50	20	−5 to 10 (Feb., '04)	−5 to 10 (Feb., '04)	230	686 to 800	S	
30 Woodhaven Water Supply Co., New York City					5	15 to 90	G	
31 Waterford	48.2	14.8 (Jan., '04)	−24 (Jan., '04)	−24 (Jan., '04)	160	30	S	
32 Yonkers	52.2	28.7	−6 (Feb., '99)		30	0 to 320	G and S	
Pennsylvania								
33 Lewiston					200	700	S	
34 Mauch Chunk	49.7	18.1	−14 (Feb., '99)		160	520 to 800	G	
35 Monessen	52.9	30.8	−20		400	750 to 1 150	S	
36 Reading	51.7	22.5	−13		101	251.5	S and G	Pa
37 Shamokin					175	730	G	
38 South Pittsburg	52.9	30.6	−20	−20	300	710 to 1 250	S	
39 Westmoreland Water Co. (Greensboro, Youngswood, Jeanette, Penn Manor, Irwin)	48.5	26	3 to 22 (Feb., '99)		350	1 000 to 1 200	S	
40 Williamsport					220	550	S and G	
41 Wilkinsburg	52.9	30.8	−20		450	900 to 1 200	S	
42 York	51.9	19.7	−17	−17	117	393	S	
Maryland								
43 Baltimore	9 to 97	24 to 36	0 (Feb., '96)		10	0 to 460	S	
Ohio								
44 Cleveland	49	−16	−16 (Feb., '99)	Water 32	406	572 to 872	S	
45 Dayton	50	12				755	G	
46 Dennison	52	10	24 (Feb., '06)		400	850	S	
47 Elyria							S	
48 Gallipolis							S	

TABLE 1.—PART I.

GENERAL DATA.

Surface or Ground Water.	Method of Distribution. Gravity or Pumping.	Elevated Storage with Pumping System. Whether Reservoir or Standpipe.	Size and Depth of Reservoir or Standpipe. (In Feet.)	Reservoir or Standpipe Open or Covered.	Capacity of Reservoir or Standpipe in Relation to Daily Consumption.	Hours of Pumping Daily in Period of Minimum Temperature.	Approximate Hourly Rate of Pumping during Winter Months.	Does Pumping Entirely Cease at Night during Coldest Weather? If Not, Give Minimum Hourly Pumping Rate.	Supply Main. Size of Main Either Gravity or Pumping. (Inches.)	If Supply is by Gravity, State Whether it is Variable or Practically Uniform.	If Variable, Give the Minimum Rate and Number of Hours.	Character of Soil. (State whether Rock, Hard Pan, Clay, Sand, Gravel, or Alluvial.)	General Depth of Ground Water. In Route of Supply Main. (Feet.)	In Distribution System. (Feet.)
th	Both	R	240 x 240 x 18	O	21 days	8	10	Yes	4 to 24	Slight	2 lbs. 6 A.M. to 8 A.M.	All	3	3
	P	S	50 x 75	O	1 500 000 gals.	24	24	No	24			All		
	P	S	30 x 100	O	528 000 gals.		24		4 to 12					
	P	S	30 x 50	O	½	24		No	16			Generally very coarse		
d G	P	R	2 500 000	O	3 days' supply	8	9	Do all pumping at night	16	Uniform		All	5½	5
	P	R				12	13	Yes	20				4½	4½
	P	R	Circular, 13 deep; 4 000 000 gals.	O	¼	12	250 000	Yes	16 and 24			S and G	Below mains	
	P and G	S	25 x 118	C	4	4	3	Yes	12 and 10			R and G	5	5
		1 R; 2 S	R, 3.1 acres, 20' S, 24 x 40	O C	½				30 to 48			Varies	Varies	
	P	2 R S	162 x 333 x 21; 94 x 94 x 18 50 x 30 Cons. 3 500 000 to 1 700 000	C	6 507 000; 1 213 000; 450 000	16	175 000	Yes	14 to 20			All	Below except for 3 000 ft.	Below
	P	R	4 300 000	O	3 to 4 times	15		Yes	19			C, S, G		
	G	R	152 A. 45' deep	O	855 000 000				16 to 30	Uniform		All	Varies	Mostly below
	P	S and Tanks	4 tanks: 37 x 73; 56 x 65; 56 x 65; 56 x 55. 2 S, 42 x 60	O	5 314 757 Total daily cons. 4 944 914	24		No	16 to 24			R, C, G		
	P	S	35 x 50	C	50%	24	24	No	12 to 14			R, Hp, S, G		
	P D and to Res.	R	30 000 000	O	5 days	24	24	No	20			R, S, G	None	
	P	R	170 x 170 x 16	O	10.5 times	10.5	300–400 gals. per min.	Yes	12 and 24	Variable	30 to 70 gals. per min.	Silt, Hp and Filling	Below except where canal water stands In some cases in canal under water	
	P	R	500 x 1 600 x 20	O	68 000 000 capacity 7 800 000 av. cons. 15 000 000 during freezing weather at times	24	10 000 000 in 24 hrs.	Every night except Sunday unless cons. is unusually heavy, then operated Sunday night.	36 and 48			Very little clay; all others	Varies	Varies
	P	S	30 x 100	C	530 000 capacity	5	31 000	Yes	12			R, S, G		
	P	S	20 x 80	O	356 000 capacity	3½	30 000	Yes	6, 10, 12			All except C	O	Ab't 1½ miles under water in winter and spring
	G								24 and 30	Variable				
	P and G	S	30 x 60	C				Yes	12			All	Low	Low
	G				90 times daily cons.				14 to 20	Variable		S, G, A	8	
	G	R			2 550 000 cap.; 9 200 000 cons.				20 and 40	Uniform		All		
	Both, mostly G	R	250 000 000; 195 000 000	O	12 to 15 days' supply either reservoir	12		Yes, but gravity supply is immediately substituted	16 to 30			Mix. C and G	Deep	Deep
	P and G	Both	R, 100 x 100 x 10 S, 25 x 20	O	Together about 1 day's supply for high service.	24	18 000	13 500	24	Variable	350 gals. per min. for short time	All	All	Usually below mains
	G								16	Variable		All	Very little	
	P and G	S	30 x 60	O	317 000	5 to 6	5 to 6	Yes	6 to 20 G 10 H S	Uniform		G	Below	In few places where mains are below river bed
	G								8 to 16	Variable	438 000 in 24 hr. for 3 hrs.	Hp, S	6±	10±
	P	R	Top 298 x 178 x 12 deep	O	4 days	12	2 000 000	Do not pump nights or Sundays	12 and 16			All	14	14
	P	R	One 7' 6" deep; one 12' deep	O	2 days	24	24	No	24			S	20	30 to 90
	P	S	30 x 51; 24 x 85	O	32.6 hrs.	16	45 000	Yes	10			All	None	None
S	P	Both	R, 22 deep S, 100	O C	8 days Cont. pumping	16 Cont.	16 Cont.	Res. Yes	18 and 24			R, Hp, S, C	None	None
	G								2, 12 1, 16 1, 16	Uniform		R, C		
	G	5 R	2 350 000	O					3 to 10	Uniform		Mostly R	Along creeks	
	P	R	85 x 30	O	1 day		60 000	45 000	10 to 12	Variable	25 000 gals., 5 hrs.	C only	None	None
	P and G	R	H S, 144 x 119 x 25; L S, 248 x 130 x 16; P S, 570 x 342 x 27	O				Yes at times	10 to 36	Uniform		R, Hp, C, G	1 up	2 up
	G				262 000 000				14 to 18	Variable		Shale and Hp	2 to 3	2 to 3
	P	S	25 x 150; 60 x 30; 25 x 50; 40 x 50; 24 x 16; 40 x 35	O	2 220 000, ½ day	24	220 000	150 000	12 to 24			C, Hp, R	None	3
	G		Greensboro H S, 2 000 000; Greensboro L S, 486 000 000; Jeanette, Penn Manor, Irwin, 76 000 000			0	0		8 to 18	Variable	6 hrs.	Various	3 to 4 6 to 8	Low points 3 to 9 High points 6 to 8
	G P	R	27 000 000; 12' deep	O		In daytime only			16 to 24	Variable	Short heavy pulls caused by R.R.	All	3	3 to 15
	P G	4 R	1, 9 500 000, 20 d'p; 1, 11 500 000, 21 d'p; 1, 5 000 000, 16 d'p; 1, 6 300 000, 17 d'p	O	Cons., 6 500 000 to 9 000 000	24	270 000 to 375 000	No	30 to 42	Uniform		C and Shale	Varies	Varies
	G	R	2 000 000, 16' deep	C	65%	12 to 24	208 000	No	20 to 24	Variable	27 000	All	25	20
	G P	S and R	2 S, 540 000 2 R, 58 500 000, 20 deep	C O	S, — 7 days R, 2.2 days							All		
	P	S and R	R, 80 400 000, 21 deep R, 33 400 000, 21 deep S, 200 000, 51 deep	O O C	114 000 000 cap. 52 050 000 cons.	24	2 000 000 to 3 000 000	1 000 000, 24 hrs.	2 to 48			All	None	None
	P					24	320 000	No; pressure kept to 60 lbs.	60			G, C, Hp	12	12
	G	R	4 600 000, 20 deep	O	3 days	24	100 000	No	12			C	12	12
	P					24	150 000		20			C, R, S, G		
	P	R	280 x 110 x 15	O	2 500 000	10	320 000	Yes	2 to 12			S, G		

TABLE 1.—PART I.

GENERAL DATA.

Temperature. Degrees Fahr.			Location of City.		Source of Supply. Surface or Ground Water.	Method of Distribution. Gravity or Pumping.	Elevated Storage with Pumping System.			Capacity of Reservoir or Standpipe in Relation to Daily Consumption.	Hours of Pumping Daily in Period of Minimum Temperature.	Approximate Hourly Rate of Pumping during Winter Months.	Does Pumping Entirely Cease at Night during Coldest Weather? If Not, Give Minimum Hourly Pumping Rate.	Supply Main.			
Mean Temperature Coldest Month.	Extreme Minimum Temperature and Date of Occurrence.	Minimum Temperature at Source of Supply and Date of Observation.	Distance from Ocean. Miles.	Elevation above Sea Level.			Whether Reservoir or Standpipe.	Size and Depth of Reservoir or Standpipe. (In Feet.)	Reservoir or Standpipe Open or Covered.					Size of Main Either Gravity or Pumping. (Inches.)	If Supply is by Gravity, State Whether it is Variable or Practically Uniform.	If Variable, Give the Minimum Rate and Number of Hours.	
10			20	210	Both	Both	R	240 x 240 x 18	O	21 days	8	10	Yes	4 to 24	Slight	2 lbs. 6 A.M. to 8 A.M.	
			40		S	P	S	50 x 75	O	1 500 000 gals.	24	24	No	24			
			40±	25±	S	P	S	30 x 100	O	528 000 gals.		24		4 to 12			
16.1	−24		85	450 to 600	G	P	S	30 x 50	O	¼	24		No	16			Ge
−24			10		S and G	P	R	2 500 000	O	3 days' supply	9	0	Do all pumping at night	16	Uniform		
−10	−10		40	900	S	P	R				12	13	Yes	20			
19	−15 (Feb. 13)	−15	40	150	G	P	R	Circular, 13 deep; 4 000 000 gals.	O	¼	12	250 000	Yes	16 and 24			
Temp. of water 50	48	48	20	111	G	P and G	S	25 x 118	C	4	4	5	Yes	12 and 10			
26.8 (Feb.)	−2 (Feb.)		On ocean	18 to 200	S		1 R; 2 S	R, 3.1 acres, 20' S, 24 x 40	O C	¼				20 to 48			
			4	10 to 365	G	P	2 R S	162 x 338 x 21; 94 x 94 x 18 50 x 30 Cons. 3 500 000 to 1 700 000	C	6 507 000; 1 213 000; 450 000	16	175 000	Yes	14 to 20			
					S	P	R	4 300 000	O	3 to 4 times	15		Yes	40			
		20	50	360 to 700	S	G	R	152 A. 45' deep	O	655 000 000				16 to 30	Uniform		
			20	270 H. pt.	S	P	S and Tanks	4 tanks: 37 x 73; 56 x 65; 56 x 65; 56 x 55. 2 S, 42 x 60	O	5 314 757 Total daily cons. 4 944 914	24		No	16 to 24			
			6	35 to 200	G	P	S	35 x 50	C	50%	24	24	No	12 to 14			
, Air Water			25	90	G	P D and to Res.	R	30 000 000	O	5 days	24	24	No	30			
					S	P	R	170 x 170 x 16	O	10.5 times	10.5	300-400 gals. per min.	Yes	12 and 24	Variable	30 to 70 gals. per min.	Si
8.6	Below zero, but not for long	−13 (Jan., '07)	Ocean	0 to 154	S	P	R	500 x 1 000 x 20	O	68 000 000 capacity 7 800 000 av. cons. 15 000 000 during freezing weather at times	24	10 000 000 in 24 hrs.	Every night except Sunday unless cons. is unusually heavy, then operated Sunday night.	36 and 48			Ve
			10	100	G	P	S	30 x 100	C	530 000 capacity	5	31 000	Yes	12			
			18	250 to 320	G	P	S	20 x 30	O	336 000 capacity	3½	30 000	Yes	6, 10, 12			
7.7	−23 (Jan., '07)	−40 (Jan., '04)	100	73 to 200	S	G								24 and 30	Variable		
					S	P and G	S	30 x 60	C				Yes	12			
3	−12 (Feb., '08)	−16 (Feb., '08)	100	150+	S	G				90 times daily cons.				14 to 20	Variable		
			44	485	S	G	R			2 550 000 cap.; 9 200 000 cons.				30 and 40	Uniform		
)	−7		Ocean	10 to 35	S	Both, mostly G	R	250 000 000; 195 000 000	O	12 to 15 days' supply either reservoir	12		Yes, but gravity supply is immediately substituted	16 to 30			
			3	0 to 150	S	P and G	Both	R, 100 x 100 x 10 S, 25 x 25	O	Together about 1 day's supply for high service.	24	18 000	13 500	24	Variable	350 gals. per min. for short time	
			15	0 to 230	S	G								16	Variable		
			150	500	S	P and G	S	30 x 60	O	317 000	5 to 6	5 to 6	Yes	6 to 20 G 10 H S.	Uniform		
			12.5	50 to 180	S	G								8 to 12	Variable	438 000 in 24 hr. for 3 hrs.	
)	−5 to 10 (Feb., '04)	−5 to 10 (Feb., '04)	230	686 to 800	S	P	R	Top 298 x 178 x 12 deep	O	4 days	12	2 000 000	Do not pump nights or Sundays	12 and 16			
			5	15 to 90	G	P	R	One 7' 6" deep; one 12' deep	O	2 days	24	24	No	16			
.8 , '04)	−24 (Jan., '04)	−24 (Jan., '04)	100	30	S	P	S	30 x 51; 24 x 85	O	32.6 hrs.	16	45 000	Yes	16			
.7	−6 (Feb., '99)		30	0 to 320	G and S	P	Both	R, 22 deep S, 100	O C	8 days Cont. pumping	16 Cont.	16 Cont.	Res. Yes	18 and 24			
			200	700	S	G								2, 12 1, 16 1, 10	Uniform		
1	−14 (Feb., '99)		100	520 to 860	G	G	5 R	2 350 000	O					3 to 10	Uniform		
8	−20		400	750 to 1 150	S	P	R	85 x 30	O	1 day		60 000	45 000	10 to 12	Variable	25 000 gals., 5 hrs.	
9	−13		101	251.5	S and G	P and G	R	H S, 144 x 119 x 25; L S, 248 x 130 x 16; P S, 570 x 342 x 27	O				Yes at times	10 to 36	Uniform		
			175	730	G	G				262 000 000				14 to 18	Variable		
	−20	−20	300	710 to 1 250	S	P	S	25 x 150; 60 x 30; 25 x 50; 40 x 50; 24 x 16; 40 x 35	O	2 220 000, ½ day	24	230 000	150 000	12 to 24			
	3 to 22 (Feb., '99)		350	1 000 to 1 300	S	G		Greensboro H S, 2 000 000; Greensboro L S, 486 000 000; Jeanette, Penn Manor, Irwin, 76 000 000			0	0		8 to 18	Variable	6 hrs.	
			250	550	S and G	G P	R	27 000 000; 12' deep	O		In daytime only			16 to 24	Variable	Short heavy pulls caused by R.R.	
	−20		450	900 to 1 200	S	P G	4 R	1, 9 500 000, 20 d'p; 1, 11 500 000, 21 d'p; 1, 5 000 000, 16 d'p; 1, 6 300 000, 17 d'p	O	Cons., 6 500 000 to 9 000 000	24	270 000 to 375 000	No	30 to 42	Uniform		
	−17	−17	117	303	S	G	R	2 000 000, 16' deep	C	65%	12 to 24	208 000	No	20 to 24	Variable	27 000	
)	9 (Feb., '08)		10	0 to 460	S	G P	S and R	2 S, 540 000 2 R, 58 500 000, 20 deep	C O	S,—7 days R, 2.2 days							
	−16 (Feb., '99)	Water 32	408	572 to 872	S	P	S and R	R, 80 400 000, 21 deep R, 33 400 000, 21 deep S, 200 000, 51 deep	O O C	114 000 000 cap. 52 050 000 cons.	24	2 000 000 to 3 000 000	1 000 000, 24 hrs.	2 to 48			
				755	G	P					24	320 000	No; pressure kept to 60 lbs.	60			
	24 (Feb., '05)		400	550	S	G	R	4 000 000, 20 deep	O	3 days	24	100 000	No	12			
					S	P					24	150 000		20			
					S	P	R	280 x 110 x 15	O	2 500 000	16	320 000	Yes	2 to 12			

	Character of Soil. (State whether Rock, Hard Pan, Clay, Sand, Gravel, or Alluvial.)	General Depth of Ground Water.		Depth to which Frost Extends in Streets.				Depth to which Frost Extends in Fields.				Average Snow Covering.	
		In Route of Supply Main. (Feet.)	In Distribution System. (Feet.)	Average Depth. (Feet.)	Maximum Depth in Gravel. (Feet.)	Maximum Depth in Clay. (Feet.)	Maximum Depth in Sand. (Feet.)	Average Depth. (Feet.)	Maximum Depth in Gravel. (Feet.)	Maximum Depth in Clay. (Feet.)	Maximum Depth in Sand. (Feet.)	In Streets.	In Fields.
.M.	All	3	3	4	5½	4	4½	1½	6			14"	2'
	All			2 to 7	4	3	4	2	4	3		2½'	2½'
				3 to 4	6	4	6	1½ to 2					
	Generally very coarse			4 to 5	7			1 to 4				1'	3'
	All	5½	5	4	5							6"	
		4½	4½	5½	5½	5½	5½	4	4½	4½	5	8"	1'
	S and G	Below mains		3	5	3	4	Good turf covering, 3 Light turf covering, 2				6"	12"
	R and G	5	8	4	4							8"	
	Varies	Varies										Varies greatly	
	All	Below except for 3 000 ft.	Below	3½ to 5								Very little	1'
	C, S, G			2 to 4									
	All	Varies	Mostly below	5	7							0" to 18"	0" to 36"
	R, C, G				6	3	6						
	R, Hp, S, G			3	5½							Very slight	
	R, S, G	None		3½	4½		5					6"	
	Silt, Hp and Filling	Below except where canal water stands. In some cases in canal under water		1½ to 3. More near canal walls								0" to 6"	3" to 18"
	Very little clay; all others	Varies	Varies	2½ to 3	Here is where we have the trouble		Not very deep					Varies	
	R, S, G				4½		3						
	All except C	0	Ab't 1½ miles under water in winter and spring	0" to 2"	4 to 6							Ab't 0"	
				3	5		4					3" to 8"	8" to 18"
	All	Low	Low	3		5							
	S, G, A	8		3	5½			2	5			2"	1'
	All			4									
	Mix. C and G	Deep	Deep	Max. 5				2½ under turf			2	2"	6"
n.	All	All	Usually below mains	2	5			1				0 to 2'	
	All		Very little	2½ to 3	5½	2½	5	1 to 2	3	2	3		
	G	Below	In few places where mains are below river bed	2½ to 3	2½ to 3			2½ to 3				0" to 12"	0" to12"
	Hp, S	6±	10±	2½		3	4					2 past years nothing	
	All	14	14	2	5	3	2½	1½				4"	0"
	S	20	30 to 90	1½			3½					Very little	
	All	None	None	5½	6	5	4½					None	
	R, Hp, S, C	None	None	1½				3				1'	1' 3"
	R, C												
	Mostly R	Along creeks											
s.	C only	None	None	1 to 1½		2		1 to 1½		2			
	R, Hp, C, G	1 up	2 up	3½		6		3					
	Shale and Hp	2 to 3	2 to 3	3	2								
	C, Hp, R	None	3				3						
	Various	3 to 4 6 to 8	Low points 3 to 9 High points 6 to 8	2 to 2½		1 to 2		1½		½ to 1			
ls	All	3	3 to 15		6	2	4	1½ to 2				4" to 6"	1' to 2'
	C and Shale	Varies	Varies	2		4+		2±		4+			
	All	25	20	1½		2½		1		1½		Very little	3' to 4'
	All												
	All	None	None		6½		5½		3 to 5	2	3 to 4		
	G, C, Hp	13	12	1				2				4"	
	C	13	13	1		3½		¾		1½		Very little	
	C, R, S, G												
	S, G			1½									

		Is Ground Likely to be Entirely Free from Snow during Days or Weeks of Coldest Weather?	If Depths are Changed in Soils of Different Character, Specify. (Feet.)	DEPTH TO WHIC					
				DEPTH TO AXIS OF PIPE.					
				Supply Mains.		Distribution System.			
				In Streets. (Feet.)	In Fields. (Feet.)	In Streets. (Feet.)	In Fields. (Feet.)		
	MAINE								
1	Auburn	Yes	5 to 6	5	4				
2	Bangor	Yes		6					
3	Brewer	Yes		6					
4	Rumford	Yes		5 cover					
	NEW HAMPSHIRE								
5	Dover	Light covering		5½	5½	4½	4½		
6	Manchester	Yes		5½	4½				
7	Nashua	No	4½ to 5 covering except in few cases where pipe is shallow. Does not freeze because of circulation.	5½	5½	5	5		
	MASSACHUSETTS								
8	Billerica	Yes		4½ cover					
9	Boston	Yes		3½ cover		5			
10	Brookline	Yes		4½ to 5½		4½ to 5½			Street sin
11	Cambridge			4 cover					
12	Fitchburg	Yes	4 to 5 of earth above pipe	7	5 to 6	7			
13	Fall River		4½ to 5. Deeper in gravel than in clay						
14	Hyde Park	Yes	4½ cover with few exceptions	3 in some cases for short distance		4½ cover			
15	Lowell	Very rarely except in St. R. R. tracks	Vary according to grade. 7 to 20	5 trench					
16	Lowell (Locks and Canals)	No	No	About 5 except in some cases 7		5½			
17	New Bedford	Yes		4 cover		4 cover			Large p be co upon tainly
18	Reading	Yes		5		5			
19	Sharon	Yes	5 to 4	5		4½			
20	Springfield	In streets Yes		About 5½. In places near surface					
21	Stoughton	Yes	Varies from 3′ 5″ to 5′ 5″ to bottom of trench						
22	Westfield	Yes		About 5½					
23	Worcester			4½ to center of pipe is usual depth					
	CONNECTICUT								
24	Bridgeport	Yes	Many places entirely exposed in sizes 12″ or larger, but unless under constant draft by gravity they are emptied	4 cover	1½ cover	4 cover	0		
25	New London	Yes	1 to 12 according to grade			4			Frost
26	Norwich	Yes		4	3	3½			Yes, ab
27	Rockville	Yes	20″ main, 2½ to 3	4 cover					No pave
28	Wallingford	Yes		4	3	4			
	NEW YORK								
29	Canandaigua	Yes		4½ cover					
30	Woodhaven Water Supply Co. New York City	Yes		3½ trench					
31	Waterford	Yes		5 to 5½ 4 to 4½ in rock					We lay 6
32	Yonkers	No		4½		4½			
	PENNSYLVANIA								
33	Lewiston	No		2½ to 3		4			
34	Mauch Chunk		No	Merely covered		3 cover			
35	Monessen	Yes		3 to 4 cover					N
36	Reading	Yes	No	3 cover. Some pipes exposed for short dist.		4 to 4½	4 to 4½		
37	Shamokin			1½ to 3 cover		3 cover			
38	South Pittsburg	Yes	No	3½ cover					
39	Westmoreland Water Co. (Greensboro, Youngswood, Jeanette, Penn Manor, Irwin)	Yes		3 cover		3½ cover			
40	Williamsport	No		3 to 6	1	5 trench			
41	Wilkinsburg	Yes		3 to 10	1 to 20	4″ to 10″, 4½′ trench; over 10″, 5½′ cover			
42	York	Yes		3 cover					
	MARYLAND								
43	Baltimore			3½ cover					
	OHIO								
44	Cleveland	Yes	No	5 to 5½		6.2 to 6.7	5.2 to 5.7		
45	Dayton	Yes		4½ cover					
46	Dennison	Yes		3½ cover					
47	Elyria	Yes		4½ to 5 cover					
48	Gallipolis			4½					

TABLE 1.—PART II.

WHICH PIPES ARE LAID.

Do You Take into Account the Effect of Different Pavements in Streets?	SERVICE CONNECTIONS. Character (describe method of connecting with main, whether tapped on top or side).	SERVICE CONNECTIONS. Size. (Inches.)	SERVICE CONNECTIONS. Depth. (Feet.)	HYDRANT BRANCHES. Size. (Inches).	HYDRANT BRANCHES. Depth. (Feet.)	HYDRANT BRANCHES. Average Length. Feet.)	HYDRANTS. State Method of Providing for Drainage.	NUMBER OF CASES OF FREEZING YEARLY. In Mains.	NUMBER OF CASES OF FREEZING YEARLY. In Services.
Yes	Side	1	6	6	5½	20	Sewerage, plug drip and pump out		3
	Side	½ to 4	6	4 to 6	7	7	Plugged	Not often	8 to 60
	Side	1	6	4 to 6	7	12	Plugged, pump out	0	4
No	Side	¾	5+	6	5	20	Nothing special required	0	10
No	45°	1 to 4	4½	6	5	10	Bottom drainage	None this last winter	None this last winter
No	Side	¾	5½	6	5½	9	None	2	10
No	Side	¾ to 2	5	4 to 10	5	8	Loose brick chamber around waste	2	6
	Top	¾ to 1½	4½	6	4½	15	Small cobbles around foot of hydrant	0	0
No		¾ to 1½	5	6 to 8	5	10	Usually through ground	None for several years	This year to date, 2
Streets have been paved since pipe was laid	Side	1	5½	6	5	10	In clay soil, gravel or chipped stones around hydrant	1 in 34 years	2 in 34 years
No	Side	¾ to 2	4½	6	4 to 4½	18	Loose stone around waste		
No	Side	¾ to 8	6	4 to 6	6	25			
No	Side	¾ to 2	4½ to 5	6 to 8	4½ to 5	10	Plug and pump out in wet ground after using	Very few	
No	Side	1	4½	6 nearly	4½	15	None but waste in hydrant	0	0
No	Side	¾ to 2	5	6	5	10	None, drains into ground. No trouble	5 in last 20 years	50 in last 20 years
No				6 to 8	5½ to 6	5 to 20	Leak hole with loose stone around hydrant	None, but occasionally some of old-style hydrants freeze	
rge pipe do not need to e covered as much, but if laid with less covering would trespass pon location of gas pipes, electric conduits, etc. Pavements cer- ainly help the frost from reaching a greater depth	Side	1½ to 2	4	4 to 6	4	8	Seldom have a frozen hydrant. Operate them late in fall and see that they properly drain. Do not open them during winter months unless absolutely necessary	Many years without a single case; then comes a cold snap and shortly have trouble with 3 or 4 dead ends	Several each year commence inside buildi and work out
No	45°	¾ to 6	Cover 4½ to 5	6 to 8	Cover 4½			0	Very few
No	Side	¾ to 1	4 to 6	4 to 6	4½	14	Drip in bottom or side near bottom	0	3 in 25 years
No	Side	¾ to 8	4½ to 5	4 to 8	5½	8	Drain into ground automatically. Base of hyd. surrounded by trap rock or screened gravel	0	1904, 53; 1905, 30; 1907, 19; 1908, 4
	Side form'ly on top	¾	3 to 5	4 to 6			Bottom drips	1	Many in 1903-4-5. Have been lowered since
No	Side	¾ to 1	4 to 6	4 to 6	4 to 5	12	Stone about drip	Very few	
No	Side	¾ to 10	4½	4 to 10	4½	8 to 12	Hyd. set in gravel or filling of loose stones set around it	0	Very few
No	Side	¾ to 12	4 cover	4 to 6	4 cover	30	Some, drip connecting sewer Some, dry well around base	Not any last 2 years	Very few except inside cellars and hous poorly plumbed
Frost less deep under pavement	Top	¾ to 4	3 to 4	6	5	18 to 20	Broken stone near bottom	0	Seldom excepting in extreme cold years in gra
es, about 6" extra depth	Part top Part 45°	¾ to ¾	3½	4 to 6	3½	10	To sewer and culverts and surrounding hydrant bases with loose stone	Practically none except 1 or more dead ends in some winters	Very few except when they begin to freeze cold cellars
paved streets. Macadam	Side	¾	3½ to 4	6	4 cover	8 to 10	Cobbles	Only at long intervals	Occasionally
No pavement	Top	¾ to ¾	4	4	4	10	Stone around drip	None in past 2 years	None in past 2 years. Where 4' deep, except sand, have had no trouble, but I find some in ro and other conditions 1½ to 2' that have frozen
No	Top	¾ to 1	4	4 to 6	4½ cover	12	Hyd. packed at bottom with about 2 bbl. of stone	1 in 14 years	Very few
No	Top			4	3½ trench	4 to 6	Waste in sand	0	No record kept
lay 6" lower under brick	Top and side	¾ to 6	4 to 5½	4 to 6	4 to 5½	25	Connect with sewer or drip made by ¼ yd. cobble and brick	3 in 1903	Numerous
No	45°	¾ to 8	4	4	4	6	Blind drainage by stoning up	7 dead ends, 1903-4	No record
No	Side	¾ and ¾	4 to 4½	4	4	14	Set on broken stone. Quantity depending on nature of ground	0	None for three years
No	Both	¾ to 2	3	4 to 6	3 cover	30	Automatic. We use Adams Patent Fire Hydrant, but occasionally have trouble in waste or drip clogging. Inspect carefully every hydrant in fall and put in good condition all hydrants	Have had none in over 20 years	4 cases in last 8 years
No pavement	Side	¾ to 1	2½ to 3½	4	3	20	Set on top of ¼ bushel of crushed stone	0	0
No	Top	¾ to 8	3½	4 to 6	4	15	¼ cu. yd. broken stone placed around barrel	2 in 10 years	Numerous
	Top	¾		4 to 6	3 to 4	20 to 30		0	0
	Top	¾ to 1	3	6	3½	12 to 36	Hydrant set in broken rock	0	
Yes	Both	¾	4	4 to 6	3½ to 5	10	Hydrant broken stone surrounding	None except bare pipe on bridges	Seldom
No	Side	¾ to ¾	5	4 to 6	5	8 to 30	Fill in around drip with gravel 2'x2'x4'	Very rare	
No	45°	¾ to ¾	4½	4 to 6	4½ to 5	3 to 8	Sump below drip of hydrant filled with about ¼ cu. yd. broken stone covered with tarred roofing paper to keep out clay	None except where street graded over main	
No	Side	¾ up	3	4 to 6	3	20	None except drip	None	2 or 3
No		¾ to 2	3+	6 to 8	3+	20	Automatic drip draining into soil		
No	45°	¾ to 6	6 cover	4 to 6	6 cover	10 ±	Stone around base of hydrant	4, 4" in 1895; 1, 4" in 1904; none in other years	2,904 frozen in 1904. None since
No	Side	¾ to 8	5	4 to 6	4½	15	Waste through drip	None	None
No	45°	¾	3½ cover	4 to 6	3½ cover	8	Tile drain to nearest sewer	None in 8 years	25 per year
No	Top	¾	4	4 to 6	4½	20	Broken stone around bottom or connecting to sewer	None	None
No	Top	¾ to 1½		6	4½	22	Drainage of bottom	None	None

TABLE 1.—PART II.

DEPTH TO WHICH PIPES ARE LAID.

DEPTH TO AXIS OF PIPE.				Do You Take into Account the Effect of Different Pavements in Streets?	SERVICE CONNECTIONS.			HYDRANT BRANCHES.			HYDRANTS.	
Supply Mains.		Distribution System.			Character (describe method of connecting with main, whether tapped on top or side).	Size. (Inches.)	Depth. (Feet.)	Size. (Inches).	Depth. (Feet.)	Average Length. Feet.)	State Method of Providing for Drainage.	
In Streets. (Feet.)	In Fields. (Feet.)	In Streets. (Feet.)	In Fields. (Feet.)									
5	4			Yes	Side	1	6	6	5½	20	Sewerage, plug drip and pump out	
6					Side	½ to 4	6	4 to 6	7	7	Plugged	
6					Side	1	6	4 to 6	7	12	Plugged, pump out	
5 cover				No	Side	¾	5+	6	5	20	Nothing special required	
5½	5½	4½	4½	No	45°	1 to 4	4½	6	5	10	Bottom drainage	None
5½	4½			No	Side	¾	5½	6	5½	9	None	
5½	5½	5	5	No	Side	¾ to 2	5	4 to 10	5	8	Loose brick chamber around waste	
4½ cover					Top	¾ to 1½	4½	6	4½	15	Small cobbles around foot of hydrant	
3½ cover		5		No		¾ to 1½	5	6 to 8	5	10	Usually through ground	None f
4½ to 5½		4½ to 5½		Streets have been paved since pipe was laid	Side	1	5½	6	5	10	In clay soil, gravel or chipped stones around hydrant	1
4 cover				No	Side	¾ to 2	4½	6	4 to 4½	18	Loose stone around waste	
7	5 to 6	7		No	Side	¾ to 3	6	4 to 6	6	25		
				No	Side	½ to 2	4½ to 5	6 to 8	4½ to 5	10	Plug and pump out in wet ground after using	
3 in some cases for short distance		4½ cover		No	Side	1	4½	6 nearly	4½	15	None but waste in hydrant	
5 trench				No	Side	¾ to 2	5	6	5	10	None, drains into ground. No trouble	5 in
About 5 except in some cases 7		5½		No				6 to 8	5½ to 6	5 to 20	Leak hole with loose stone around hydrant	
4 cover		4 cover		Large pipe do not need to be covered as much, but if laid with less covering would trespass upon location of gas pipes, electric conduits, etc. Pavements certainly help the frost from reaching a greater depth	Side	1½ to 2	4	4 to 6	4	8	Seldom have a frozen hydrant. Operate them late in fall and see that they properly drain. Do not open them during winter months unless absolutely necessary	Many years then comes a have trouble
5		5		No	45°	¾ to 6	Cover 4½ to 5	6 to 8	Cover 4½			
5		4½		No	Side	¾ to 1	4 to 6	4 to 6	4½	14	Drip in bottom or side near bottom	
About 5½. In places near surface				No	Side	¾ to 3	4½ to 5	4 to 8	5½	8	Drain into ground automatically. Base of hyd. surrounded by trap rock or screened gravel	
					Side form'ly on top	¾	3 to 5	4 to 6			Bottom drips	
About 5½				No	Side	¾ to 1	4 to 6	4 to 6	4 to 5	12	Stone about drip	
4½ to center of pipe is usual depth				No	Side	¾ to 10	4½	4 to 10	4½	8 to 12	Hyd. set in gravel or filling of loose stones set around it	
4 cover	1½ cover	4 cover	0	No	Side	⅝ to 12	4 cover	4 to 6	4 cover	30	Some, drip connecting sewer Some, dry well around base	Not a
		4		Frost less deep under pavement	Top	¾ to 4	3 to 4	6	5	18 to 20	Broken stone near bottom	
4	3	3½		Yes, about 6" extra depth	Part top Part 45°	¾ to ⅞	3½	4 to 6	3½	10	To sewer and culverts and surrounding hydrant bases with loose stone	Practically dead ends in
4 cover				No paved streets. Macadam	Side	¾	3½ to 4	6	4 cover	8 to 10	Cobbles	Only a
4	3	4		No pavement	Top	⅝ to ¾	4	4	4	10	Stone around drip	None
4½ cover				No	Top	¾ to 1	4	4 to 6	4½ cover	12	Hyd. packed at bottom with about 2 bbl. of stone	1
3½ trench				No	Top			4	3½ trench	4 to 6	Waste in sand	
5 to 5½ 4 to 4½ in rock				We lay 6" lower under brick	Top and side	¾ to 6	4 to 5½	4 to 6	4 to 5½	25	Connect with sewer or drip made by ¼ yd. cobble and brick	
4½		4½		No	45°	¾ to 3	4	4	4	6	Blind drainage by stoning up	7 dea
2½ to 3		4		No	Side	¼ and ½	4 to 4½	4	4	14	Set on broken stone. Quantity depending on nature of ground	
Merely covered		3 cover		No	Both	¼ to 2	3	4 to 6	3 cover	30	Automatic. We use Adams Patent Fire Hydrant, but occasionally have trouble in waste or drip clogging. Inspect carefully every hydrant in fall and put in good condition all hydrants	Have had n
3 to 4 cover				No pavement	Side	¼ to 1	2½ to 3½	4	3	20	Set on top of ½ bushel of crushed stone	
3 cover. Some pipes exposed for short dist.		4 to 4½	4 to 4½	No	Top	¼ to 3	3½	4 to 6	4	15	½ cu. yd. broken stone placed around barrel	2 f
1½ to 3 cover		3 cover			Top	¼		4 to 6	3 to 4	20 to 30		
3½ cover					Top	¼ to 1	3	6	3½	12 to 30	Hydrant set in broken rock	
3 cover		3½ cover		Yes	Both	¼	4	4 to 6	3½ to 5	10	Hydrant broken stone surrounding	None except
3 to 6	1	5 trench		No	Side	¼ to ½	5	4 to 6	5	8 to 20	Fill in around drip with gravel 2'x2'x4'	V
3 to 10	1 to 20	4" to 10", 4½' trench; over 10", 5½' cover		No	45°	¼ to ½	4½	4 to 6	4½ to 5	3 to 8	Sump below drip of hydrant filled with about ½ cu. yd. broken stone covered with tarred roofing paper to keep out clay	None except over main
3 cover				No	Side	¾ up	3	4 to 6	3	20	None except drip	
3½ cover				No		¾ to 2	3+	6 to 8	3+	20	Automatic drip draining into soil	
5 to 5½		6.2 to 6.7	5.2 to 5.7	No	45°	¼ to 6	6 cover	4 to 6	6 cover	10 ±	Stone around base of hydrant	4, 4" in 18 none f
4½ cover				No	Side	¼ to 3	5	4 to 6	4½	15	Waste through drip	
3½ cover				No	45°	¾	3½ cover	4 to 6	3½ cover	8	Tile drain to nearest sewer	None
4½ to 5 cover				No	Top	¾	4	4 to 6	4½	20	Broken stone around bottom or connecting to sewer	
4½				No	Top	¼ to 1½		6	4½	22	Drainage of bottom	

Number of Cases of Freezing Yearly.		Are the Depths of Pipe in Your Judgment generally Sufficient except under Extreme Conditions of Temperature?	Do These Unusual Conditions Occur with Sufficient Frequency to Justify a General Lowering of the Pipe System?
In Mains.	In Services.		
	3	Yes	No
Not often	8 to 60	Yes	No
0	4	Yes	No
0	10	Yes	No
None this last winter	None this last winter	Yes, except in extreme cold weather. We had service pipe freeze in gravel 5′ 9″ under ground, winter 1906	No
2	10	Yes	No
2	6	Yes	No
0	0	Yes	No
None for several years	This year to date, 2	Yes, under any conditions that have obtained since 1895	No
1 in 34 years	2 in 34 years		
		Yes	No
Very few		Yes	No
0	0	Yes	No
5 in last 20 years	50 in last 20 years	Yes, most cases have occurred where grade of street was lowered, leaving pipe shallow, i. e., less than 5′ to bottom of pipe and during a long period of zero weather with little snow on ground	No
None, but occasionally some of old-style hydrants freeze		Yes	No
years without a single case; omes a cold snap and shortly rouble with 3 or 4 dead ends	Several each year commence inside building and work out	Four feet is a good depth for this locality. I should not want to make it any less, and certainly should not advise greater depth	No
0	Very few	Yes	No
0	3 in 23 years	Yes, some parts of system, i. e., around Lake Massapoag, are laid about 3′ 6″ to 3′ 9″ to axis of pipe, but during winter and spring are covered with water	No
0	1904, 53; 1905, 30; 1907, 19; 1908, 4	Yes	No
1	Many in 1903-4-5. Have been lowered since	Yes	No
Very few		Yes	No
0	Very few	Yes	No
Not any last 2 years	Very few except inside cellars and houses poorly plumbed	They are; we lay all sizes in the city with 4′ of cover and think this sufficient even in extremely cold weather long continued	No
0	Seldom excepting in extreme cold years in gravel	Yes	No
ically none except 1 or more nds in some winters	Very few except when they begin to freeze in cold cellars	While experience so far as mere expense is concerned does not so indicate on account of occasional inconvenience and possibility of more, a depth of 4½′ to axis is recommended	Not so far as pipes already laid are concerned
Only at long intervals	Occasionally	Yes	No
None in past 2 years	None in past 2 years. Where 4′ deep, except in sand, have had no trouble, but I find some in rock and other conditions 1½ to 2′ that have frozen	Yes	No
1 in 14 years	Very few	Yes	No
0	No record kept	Yes	No
3 in 1903	Numerous	Yes, except where services are tapped on top of main	No
7 dead ends, 1903-4	No record	Yes	No
0	None for three years	Yes; we endeavor to have every main circulate by eliminating dead ends, and where we must have a dead end we provide a blow-off which we open during extreme cold weather	
had none in over 20 years	4 cases in last 8 years	Yes; under the conditions of opening drain gates, at low points and various ends or terminations of mains to cause a constant circulation during winter months. Some gates are used for flushing out mains, as in our judgment it seems necessary at any time after fall and spring rains	
0	0	Yes	No
2 in 10 years	Numerous	Yes	No
0	0	Yes; we have never had any mains freeze except in one or two cases where street was cut down and we neglected to lower pipe	
0		Yes	
xcept bare pipe on bridges	Seldom	Yes; no trouble with mains except on bridges and exposed places; 9% of frozen service pipes due to plumbers' "skinning" work, mostly at cellar wall	No
Very rare		Yes	No
xcept where street graded in		Yes	
None	2 or 3	Yes; we do not lower our mains when grades are changed except where covering over pipe is reduced to less than 27″	No
		Yes	No
″ in 1895; 1, 4″ in 1904; none in other years	2,904 frozen in 1904. None since	Yes	No
None	None	Yes	No
None in 8 years	25 per year	Yes	No
None	None	Yes	
None	None	Yes	No

		Temperature. Degrees Fahr.				Location of City.				Elevated Storage with Pumping System.				
		Mean Yearly Temperature.	Mean Temperature Coldest Month.	Extreme Minimum Temperature and Date of Occurrence.	Minimum Temperature at Source of Supply and Date of Observation.	Distance from Ocean. Miles.	Elevation above Sea Level.	Source of Supply. Surface or Ground Water.	Method of Distribution. Gravity or Pumping.	Whether Reservoir or Standpipe.	Size and Depth of Reservoir or Standpipe.	Reservoir or Standpipe. Open or Covered.	Capacity of Reservoir or Standpipe in Relation to Daily Consumption.	Hours of Pumping Daily in Period of
	Ohio													
49	Hamilton							G	G and P	R	3 000 000; 20′ deep	O	Consumption 2 500 000	
50	Jackson						605	G	G	S	30 x 50	O		1
51	Loraine	50.4	18	–10 (Feb.)		475	605	S	P					2
52	Marietta					500	607	S	P	2 R 2 S	1 272 334 60 x 30	O	Consumption 2 300 000	2
53	New Philadelphia			– 21				G	P	R	2 000 000	O	2 times	1
54	Lima	51.6	19.4	– 20.5 (Feb., '99)		700		S	P	R	Storage, 400 000 000 Dist., 120 000 000	O	Consumption 3 000 000	2
55	Oberlin	49.1	25.8	– 21 (Jan., '84)		500	810	S	P	S	18 x 35	C	1 to 3	6
56	Springfield	56	0	– 20 (Feb., '96)	– 22	750	700	G	P	S	30 x 120	O	592 000	2
57	Warren	50.5		–11 (Feb.)			885	G	P	S	23 x 140	O	½	2
	Indiana													
58	East Chicago					1500		S	P	S	16 x 100	O		1
	Illinois													
59	Belleville					1000	531	G	P	S	26 x 120	C	¼	1
60	Elgin			– 15		985	737	S G	P					2
61	Mattoon	55.3	30.4	– 32	– 32		726	G	P G	S R	R, 150 000 S, 15 x 120	C	10 times	
62	Peoria	50	23.1	– 22 (1899)		800	440 to 750	G	P	R	20 to 38′ deep	O	4½ times	20 t
63	Quincy	55	20.5	–22 (Feb.)		750	350	S	P	R	320 x 420 x 26	O	10 days	7
	Wisconsin													
64	Ashland	40	6.2		– 32 (Jan., '04)	1000	602 to 630	S	P	O				1
65	Milwaukee	43	33.3	– 18 (Feb., '05)	35	1000	591 to 750	S	P	R S	R, 21 000 000; 20′ deep S, 4′ diameter	O C	Reservoir, 20 000 000 Consumption, 30 000 000	2
	Michigan													
66	Ann Arbor			– 6	– 6	800	850	G	G	R	250 x 100 x 17	O	3 000 000	2
67	Grand Rapids	48.1	23.6	– 24 (Feb., '99)			589	S	P	R, H S S, L S	R, 5 000 000 S, 75 x 30 T, 60 x 30	R S, O T, C	13 500 000	2
68	Ludington							S	P					2
	Iowa													
69	Burlington	51.2	29.7	– 27 (Feb., '05)		1100	525 to 675	S	P					2
70	Centerville	50	24.5	– 5		1200	1000	G	P	S R	R, 10 x 60 S, 12 x 100	C	R, 3½ days S, 1½ days	2
71	Mason City			– 34 (Feb., '05)			1350	G	P	R	180 x 34 x 20	C	500 000 gallons capacity 40 000 gallons consumpt'n	2
72	Muscatine	49.4	22.6	17 (Feb., '91)	– 33 (Jan., '84)	1200	538	G	P	R	250 x 20 x 20	O	2 000 000	1
	Wyoming													
73	Green River and Rock Springs supplying several towns, inc. Union Pacific Water Co.			– 40 to 45 (Jan. or Feb.)		1100	6260	S	P (L	R		O	Green River 2 days	U P W as req Green
	Washington													
74	Everett	51.5	30	0	0	Ocean	100	G	P	R	14′ 8″ deep 1 225 000 gal.	O	2 020 000 gallons	1
75	Hoquiam	40 to 60		10 (Jan., '09)		16	0	S	P	R	4 500 000; 21′ deep	O	3 days	2 2
	Canada													
76	Charlottetown, P. E. I.	42				Ocean	10 to 50	G	P G	R	1 250 000	C	2	6
77	Yarmouth, N. S.	44	25			1½	65	S	P G	R	175′ 5″ x 125′ 5″ x 18′	O		2
78	Montreal, P. Q.	42	12				50 to 175	S	P	R		O	1 day	2
79	Brantford, Ont.	50						G	P					2
80	Kingston, Ont.	44.6	19.1	– 19		300	285	S	P	S	40 x 80	O	626 000 capacity 2 300 000 consumption	
81	London, Ont.	46.3	29.1	– 20 (Feb., '08)	– 20	580	810	G	P	R	290 x 290 x 13.5	O	36 hours	2
82	Pembroke, Ont.					1000	380 to 400	S	P	S	60 x 20	O	¼	1
83	St. Catherines, Ont.			– 18 (1904-5)	– 18	450	300	S	G				365 000 000 2 739 000	
84	Winnepeg, Man.	36	13		– 53.5 (Dec., '79)	1500	756	G	P	R	6 000 000	C	1½ times	2
85	Regina, Sask.		– 20	– 50 (Feb.)	– 50 (Feb.)	1250	1885	G	P	R	1 100 000	C	50% greater	2
86	Edmonton, Alta.	37	8	– 30 (Dec., '08)	– 36	900	2240	G	P					2
	New York													
87	Rochester	47.25	24.1	– 14 (Jan., '04)	– 8 (Feb., '08)	250	510	S	G P	R	142 000 000; 25′ deep 22 500 000; 10′ deep	O	10	2

LE 1.—PART III.

Hours of Pumping Daily in Period of Minimum Temperature.	Approximate Hourly Rate of Pumping during Winter Months.	Does Pumping Entirely Cease at Night during Coldest Weather? If Not, Give Minimum Hourly Pumping Rate.	Supply Main. Size of Main, Either Gravity or Pumping. (Inches.)	Supply Main. If Supply is by Gravity, State Whether It is Variable or Practically Uniform.	Supply Main. If Variable, Give the Minimum Rate and Number of Hours.	Character of Soil. (State whether Rock, Hard Pan, Clay, Sand, Gravel or Alluvial.)	General Depth of Ground Water. In Route of Supply Main. (Feet.)	General Depth of Ground Water. In Distribution System. (Feet.)	Depth to which Frost Extends in Streets. Average Depth. (Feet.)	Depth to which Frost Extends in Streets. Maximum Depth in Gravel. (Feet.)	Depth to which Frost Extends in Streets. Maximum Depth in Clay. (Feet.)	Depth to which Frost Extends in Streets. Maximum Depth in Sand. (Feet.)	Depth to which Frost Extends in Fields. Average Depth. (Feet.)	Depth to which Frost Extends in Fields. Maximum Depth in Gravel. (Feet.)	Depth to which Frost Extends in Fields. Maximum Depth in Clay. (Feet.)	Depth to which Frost Extends in Fields. Maximum Depth in Sand. (Feet.)	Average Snow Covering. In Streets. (Inches.)	Average Snow Covering. In Fields. (Inches.)
	8	Yes	16 to 20			All	2½ to 3	2½ to 3		3							Very little	
18	22	No	10	Variable		R Hp C A	2½	4	1½				1½					
24	125 000	No	12 to 24			C		2			3							
20	9 582	5 hours at night	12			S A	20	20	1½								6	
12	18	Yes	12	Uniform		G S			2 to 3	2 to 3		2 to 3	1½ to 2	1½ to 2		1½ to 2	2	5
24	125 000	25 000	20			C	25	25	3½		3½		3½		3½			
6	35 000	Yes	12			C	None	None		None	2½	None			½		Little	
22	154 200	2 hours	24	Variable		R C G	None	None	2	3	3½		3	3	3½		4	4
20	45 000	Yes	16			C	None	None	2 to 3		2 to 3		1				3	6 to 8
24	24	No	16			S	0 to 6	0 to 6	1½ to 4			5½					3	
16	50 000	Yes	12 to 20			C	Below	Below										
24		No	16 to 24						2 to 6	2½			1½ to 5	5½	3 to 4	3 to 4	Very little	
		Yes	12			A	2 to 6	2 to 6	2½								0	0
20 to 24	150 000 160 000	Yes	30	Variable	25 30 000	C S G			2½	4	2	4					10	12
7½	200 000	Yes	20			C R	15 to 30		1			2½		1½		3	2	
24	550 000	No	12 to 20			C			5		7		2				6 to 20	2' 0"
24	24	No	7½	Supply tunnel under lake		C	4		4½	6	3½	6					6	
24	24	No	12 to 16	Uniform		G C	30 to 50		3	3	3	3	1	1	1	1	6	6
24	13 500 000 24 hr.	No	12 to 30			All												
24	24	25 000	8 to 16			S		3 to 15				2½	4			10"	1'	2 to 6
24	75 000	No	12 to 16			C	Below	Below	2½		4 to 5				3½			
2	28 600	Yes	4 to 6	Variable	12 hours at 13 000 per hour	C	15 to 30	15 to 30	1½ to 2									
24	24		16			C R	4		4½		4							
10	10	12 hours	16			C S Hp	3	1 to 2	3	4	2 to 4	3 to 4½	3	4	2 to 4	3 to 4½	2 to 6	4" to 1'
U F W Co. as required Green R. 24	40 000	U F W Co., Yes Green R., No	8 to 12	Uniform		E G C	None	None	4½				4½				Very little	
15	100 000	Yes	22			C S Hp	2	8	1	1	1	1	6"	6"	6"	6"	2	2
20 24		No	10 to 14			A C	0	3	6"	3"	6	3	Slight				Very little	
8	86 000	Yes	14	Uniform		C R			4		4½		4		4½		2"	2"
20		No	12	Variable		R C G			1½	2	2	2	1				2	
24	3 000 000	No	2, 30 3, 24			Variable			4½ to 5	7	5	6	1½	2	1½	1½	3'	3'
24	2 500 000 daily	No	10 to 14			S G	6	5½	2 to 4	6		6	1				1' to 1½'	1 to 1½'
			16			R C	7	7	4½		5½						1'	
24	158 300	No	18	Variable		Hp S G C	25 to 30	15	4	4½	4½	6½	2½	3½	2½	4"	9	1½'
15	26 600	Yes	8			All except E			4	6	5	4	3				15	2½'
			16 to 20	Variable	30% less during night	All	0 to 170	0 to 16	3	3	2½	2 to 5	3	None	3	3	4	4
24	6 600 000 24 hrs.		12 to 20			C			7		8		6 to 8		8		1 to 1½'	1½'
24	20	No	10	Uniform		G C	12	None	5 to 6		5 to 6		4		5		6	6
24	85 000	75 000	12			C	None	None	4 to 8		8				4		4	10
24	1 600 000	No 500 000±	20 24, 36	Uniform		Varies, generally S	0 to 50	20	2 to 3				1½				0	1'

		Is Ground Likely to be Entirely Free from Snow during Days or Weeks of Coldest Weather?	DEPTH TO WHICH PIPES ARE LAID. If Depths are Changed in Soils of Different Character, Specify.	DEPTH TO AXIS OF PIPE. Supply Mains. In Streets.	Supply Mains. In Fields.	Distribution System. In Streets.	Distribution System. In Fields.	Do You Take into Account the Effect of Different Pavement in Streets?	SERVICE CONNECTIONS. Character (describe method of connecting with main, whether tapped on top or side).	Size.	Depth.	HYDRANT BRANCHES. Size.	Depth.	Average Length. HYDRANT BRANCHES.	HYDRANTS. State method of provid for drainage.
	OHIO														
49	Hamilton			5′					Top	Less than 1″	4′–5′			25	
50	Jackson	Yes	No					No	Top	¾″–2″		6″	4½′	12′	Crushed stone
51	Lorain			5′				No	Side	¾″–1″		6″	5′	12′–14′	Loose stone
52	Marietta	No		4½′		3′		No	Top	¾″–1″	3½′–3′	4″–6″	3′–4′	12′	Bowlders placed around bot
53	New Philadelphia	Yes		4′	4′	4′	4′	No	Top	¾″–1″	4′	6″	4′	12′	Gravelly soil. No troubl
54	Lima	No		5′ 10″	6′	5′ 10″	6′	No	Top	¾″–6″	4′	6″	5′	10′	Pump out after using
55	Oberlin	Yes				5′ cover		No		¾″	4′	4″	6′	15′	Broken stone around dri
56	Springfield	Yes		4′ cover		4′ cover		No		¾″–1″	4′	6″	4′	12′	
57	Warren	Yes		5′ trench		5′ trench		No	Side	¾″–¾″	3′–4½′	6″	5′	11′	½ bushel stone or brick
	INDIANA														
58	East Chicago	Yes		2′–4′		3½′		No	Side	¾″	3′–4′	4″–6″	3′–4′	12′	Drip
	ILLINOIS														
59	Belleville			3′ cover				Yes	Top	¾″	3′ cover	4″–6″	3′ cover	8′	Brick bats, crushed rock
60	Elgin	Yes		6′ cover				No	Side	¾″–1½″	6′–7′	6″	6′ 6″	12′	Drain a few
61	Mattoon	Yes		3′ cover				No	45°	¾″–1″	3′	4″	3′ 6″	12′	Broken brick or crushed st
62	Peoria	Yes		5′ cover				No	45°		5′	4″–10″	5′	7′–15′	Base of hydrant set on or brick. 2 cu. ft. brick ba broken stone
63	Quincy	Yes		4½′ cover				No	45°	¾″–1″	4½′	6″	4½′	14′	Stone or gravel around holes
	WISCONSIN														
64	Ashland	No		6′ cover				No	Side	¾″–2″	6′	4″	6′	16′	Hydrant plugged and hy pumped dry on account of face water collecting in tren
65	Milwaukee	Yes		6′ 6″		6′		No	Side	¾″–2″	6′ 6″	6″	6′	10′	Connect with sewer
	MICHIGAN														
66	Ann Arbor	Yes		5′	5′			No	Top	¾″–1″	6′	6″–8″	6′	12′	Cast-iron drip box
67	Grand Rapids	Yes		5′ 9″		5′ 9″					6′ in streets 5′ in lawns	6″	7½′	16′–18′	
68	Ludington	Yes		4′ cover				No	Side	¾″–2″	4′	4″	4′	10′	Connect with sewer where sible. Pit filled with b stone where no sewer
	IOWA														
69	Burlington	Yes		5′ 6″ cover				No	Side			4″–6″	5′ 6″ cover	14′	Pump out in fall and fires in winter
70	Centerville	Yes		4.5 ft.					Top	¾″–1¼″	4′	4″	4.5′	7′–10′	Drip. No connection to or other drain
71	Mason City	Yes		6′ trench				No	Side	¾″–1″	6′	4″	6′	8′	If dirt soil, we use stone a hydrant for drainage
72	Muscatine	Yes		6′				No	Both	¾″–6″	6′	6″	6′	7′	By rock with cover of straw
	WYOMING														
73	Green River and Rock Springs supplying several towns, inc. Union Pacific Water Co.	Entire winter		5′ cover				No	Top	¾″–1″		4″		40′	Medium sized rock
	WASHINGTON														
74	Everett	Yes		3′	2′	2′ 10″	2′ 10″	No	45°	½″–2″	2′	4″–8″	2′ 10″	10′	Coarse gravel
75	Hoquian	Yes		3′		2½′		Yes	Top	¾″–1″	1½′	6″	2½′	20′	Gravel and stone around
	CANADA														
76	Charlottetown, P. E. I.	Yes		5′ cover				No pavement	Side	¾″–1″	5′	6″	5′	20′	No drainage required o count of nature of soil
77	Yarmouth, N. S.	Yes		4′				No	Side	¾″–1″	3′ 3″	6″	4′	10′	Sewers when convenient. sewers, plug drip and pump
78	Montreal, Que.	No		4′ 9″–5′		6′ trench		No	Top	¾″–1″	6′	4″–8″	6′	0′–8′	Drip drains to street sew
79	Brantford, Ont.	Yes	In gravel deeper In clay not so deep	12′–18′		5½′ cover		No	Both	½″	5½′ cover	6″	5½′ cover		Vent hole at foot and a in with pit gravel at botto
80	Kingston, Ont.	Yes	Pipes laid 6″ deeper where excavation is all rock	5′		5′		No pavement	Side	¾″–1″	5′–5½′	6″	5′–6′	12′	3″ old boiler tube to sewe
81	London, Ont.	No	No	5′ cover				No	Top	¾″	5½′	6″	5′ cover	12′	Protected by stone and g placed around bottom of hy
82	Pembroke, Ont.	No		5½′		5′ 9″		No	Both	¾″–1″	6′	4″–6″	5½′	6′	Connect to sewers or su drains, also by seepage
83	St. Catherines, Ont.	Yes		5′ cover				No	Both		6′	6″	5′ cover	25′	In gravel, none. In drain to sewer. Where no s drips are plugged and hy pumped when used.
84	Winnepeg, Man.	Yes		6′–10′		6′–10′		No	Side	¾″		6″–8″	8′	23′	Drip connection with sew
85	Regina, Saskatchewan	Yes		8′		8′	8′	No	Side	¾″–2″	7½′	6″	7½′	4′	Tile drain to sewer
86	Edmonton, Alberta	Yes		8′ cover				No	45°	¾″–2″	7½′–8′	6″	8′	30′	Drain to sewer
	NEW YORK														
87	Rochester, N. Y.	Yes	No	5′–6′		5′–8′			Side	¾″–2″	4½′ cover	4″–8″	4½′	7′	3″ tile to sewer

— PART IV.

providing	Number of Cases of Freezing Yearly. In Mains.	In Services.	Are the Depths of Pipe in Your Judgment generally Sufficient except under Extreme Conditions of Temperature?	Do These Unusual Conditions Occur with Sufficient Frequency to Justify a General Lowering of the Pipe System?
	0	0	Yes	No
ne	0	0	More than sufficient	No
e	0	196	Yes	No
und bottom	0	Only in residences	Yes	No
o trouble	0	6	Yes	No
using	None	None	Never had any freezing	No
und drip				
	1	Only in houses	Yes	No
brick	0	Generally none. 3 or 4, 4 years ago	Yes	No
	None since winter, 1903	Several, but becoming less each year	Yes	No
d rock	One in 8 years	10 in 8 years	Yes	No
	0	0 in 10 years		No
shed stone	0	0	Yes	No
et on stone rick bats or	None in 16 years except March, 1899	0	The pipes which froze had 3′ to 4′ cover, which is hardly enough or dead ends. Five feet I think, is more than enough, and cover has recently been specified as 4½′ for further extensions.	No
ound waste	0	0	Yes	
nd hydrant unt of sur- in trenches	0	5	Yes	No
ewer	0	0	Yes	No
box	0	0	Yes	
			Old mains laid in trench 4′ to 5′ deep, which did not prove sufficient.	We are lowering mains except large ones to at least 5′ cover as streets are being re-improved.
where pos- th broken	0		Yes. Eight years ago temperature dropped to 40° below zero for two weeks. Frost went below mains on paved streets. First time in twenty-five years this has occurred.	No. With our sand, frost will not penetrate the ground for depth except under a paved or hard-packed street. The flow of water is sufficient to keep mains clear.
and after	0	Few cases, 1903, '04, '05. Since then very few	Yes. In a few cases we found city had changed the grades of streets before laying brick pavements, leaving the mains with only 3′ 6″ or 4′ cove for short distances. Have had no trouble with mains in such place, but hydrant and services in these shallow places have been frozen.	Our judgment is that in this city we should have not less than 5′ cover over services and hydrant branches.
ion to sewer	0	None in streets. All cases in houses or near surface of ground	Yes. Have had some mains but 12″ to 15″ underground where streets were graded. These did not freeze last winter, 1907.	No
one around e	None except in 1905		Yes	No
f straw	0	In extreme winters, 25	Yes	No
ock	None in recent years		Yes	No
	0	0	Yes	No
round base	0	Many in exposed places with no covering	Yes	No
ed on se-	0	0	Yes	No
lent. No ump	0	2 in 10 years	Yes	
sewer	Very few	300 to 500 every winter	Yes. Most frozen services occur in severe winters when the ground surface is denuded of snow, and it is generally found that the pipes have not the regulation depth of 6′, due generally to change of grade for street pavement, perhaps long after services were laid.	I should say not. I believe if all our services were laid to 6′ depth there would be very few cases of freezing. I would not advise la[illegible] them at a lesser depth in our climate
nd all put ottom	0	0		
sewers	0	Average, 10 for 20 years	Yes, for our conditions; 75% of pipes are in rock excavation. To put them deeper would increase cost much more than earth excavation and would interfere with sewers, which average 6′ 6″ deep.	If a main freezes at any time, it should be put deeper
nd gravel f hydrant	0	0	Yes	No
r surface	None since 1893	Practically none; 1 in 1908	There has never been a case of either supply mains or distribution mains freezing. Services have occasionally frozen when no snow was on roadway and temperature about 35° below.	No
In clay, no sewer, hydrant	None since 1900	None except in severe winter, 1904–05	Yes	No
h sewer			Sufficient in all cases where there is circulation. Dead ends only freeze.	No
er	0	2%	Yes	No
	1	During the winter months 154 house services were frozen. The greater percentage of these were on the property where the 8′ depth is not always adhered to. I should say that about 4 to 6 were frozen outside the street line, mainly caused by freezing at service casing and thence working into pipe. I have also found occasions where pipes froze on the property and the frost worked back into street pipes.	Yes	No
	0	Ordinary years, 5; 1902–3, 100±. In very few cases is a service ever found frozen which has been laid properly at our stated depth of 4½′ cover. This explanation must be made, however, that there are always a number of services frozen every year in the basements or cellars of houses where proper precautions are not taken, and the freezing process extends out through the cellar wall into the service in the above-mentioned statistics of frozen services.	

depth at which the pipes should be laid. In 10 per cent. of the replies it appears that some attention is paid to the character of the street surface, although apparently there is no prevailing rule. Some consider that a pavement is equal to one foot of cover; others that pipe should be laid deeper in a paved street. An average of the replies received indicates that freezing extends one foot deeper in streets than in fields; also that in streets frost will reach 1 foot 5 inches deeper in gravel than in clay, with sand half way between. In fields it would appear that frost will extend one foot farther in gravel than in clay, with sand again intermediate in effect. It is obvious that the character of the soil is a factor of such relative importance as to demand consideration in determining the economical depth.

Fifty-three places report actual experience in the freezing of pipes. All of these cases were in distribution systems and none in the leading mains. Fifty per cent. were on dead ends and all were in pipes where there was little or no velocity. All but three of the cases of freezing were in pipes smaller than 10 inches in diameter, only seven in pipes as large as 8 inches in diameter; in all cases the ground was frozen below the axis of the pipe, and the ground water level was also below the pipe. In 80 per cent. of the cases the ground was bare of snow at the time of freezing. All stoppages were total. Thirty-five places report the character of the earth in which the pipes were laid; of these, 40 per cent. were in clay, 48.6 per cent. in gravel, 5.7 per cent. in sand, and 5.7 per cent. in rock.

Table 3 shows the latitude, average yearly and minimum temperatures (based on the United States Government Reports) of the places from which replies were received and also the depths at which the pipe was laid in these places. Obviously the temperature depends on other factors than latitude, and, believing that the mean temperature of the coldest month would provide a more satisfactory basis of comparison, a diagram, Fig. 1, with this temperature as the scale of the horizontal coördinate, and the depth, as reported, as the vertical coördinate, has been prepared. On this diagram the different places, from which replies were received, have been plotted. There is much variation in the relation of depth to temperature of coldest month, as indicated by the practice

TABLE 3.

TABLE OF CITIES AND TOWNS, ARRANGED IN ORDER OF THEIR LATITUDE, GIVING AVERAGE YEARLY AND MINIMUM TEMPERATURE, BASED UPON UNITED STATES GOVERNMENT REPORTS, AND DEPTH TO CENTER OF PIPE IN DISTRIBUTION SYSTEM.

	Lat. Approx.	Temperature.		Depth to Center of Pipe.
		Av. Yearly.	Minimum. Extreme.	
Edmonton, Alberta	53.5	37.0±	—30±	*8.0
Regina, Saskatchewan	50.5	36.0±	—50±	*7.5
Winnepeg, Man.	50.0	36.0±	—53.5±	7–8
Everett, Wash.	48.0	52.0±	24±	2.83
Hoquiam, Wash.	47.0	51.0±	18±	2.5
Ashland, Wis.	46.5	40.0±	—32±	*6.0
Charlottetown, P. E. I.	46.2	42.0±	.....	*5.0
Pembroke, Ont.	45.8	....	.....	5.75
Montreal, P. Q.	45.5	42.0±	.....	†6.0
Bangor, Me.	44.8	43.6±	—21±	6.0
Brewer, Me.	44.8	43.6±	—21±	6.0
Rumford, Me.	44.5	43.1	—17	*5.0
Belfast, Me.	44.4	43.6±	—21±	6.0
Kingston, Ont.	44.2	44.6±	—19±	5.0
Auburn, Me.	44.1	45.0±	—11±	4–5
Ludington, Mich.	44.0	46.0±	—10	*4.0
Yarmouth, N. S.	43.6	44.0±	.....	4.0
Rochester, N. Y.	43.2	48.6	—3	4.75–8.0
Mason City, Ia.	43.2	47.4	—13	6.0
Brantford, Ont.	43.1	50.0±	.....	*5.5
St. Catherines, Ont.	43.1	...	—18±	*5.0
Dover, N. H.	43.1	46.0±	—10±	4.5
Manchester, N. H.	43.0	46.0±	—10±	4.5–5.5
Milwaukee, Wis.	43.0	47.9	—1	*6.0
Grand Rapids, Mich.	43.0	48.7	—6	5.75
London, Ont.	43.0	46.3±	—20±	*5.0
Canandaigua, N. Y.	42.9	49.0±	—3±	*4.5
Waterford, N. Y.	42.8	49.0±	—10±	5–5.5
Nashua, N. H.	42.8	47.7	—8	5.0
Billerica, Mass.	42.6	50.0±	—3±	*4.5
Fitchburg, Mass.	42.6	47.9	—5	*4–5
Lowell, Mass.	42.6	49.6	—3±	†5.0
Lowell (locks and canals), Mass.	42.6	....	.....	5.5
Reading, Mass.	42.6	50.0±	—3±	5.0
Ann Arbor, Mich.	42.5	49.1	—4	5.0
Boston, Mass.	42.4	50.0	—1	5.0
Brookline, Mass.	42.3	50.0±	—1±	4.5–5
Cambridge, Mass.	42.3	50.0±	—1±	*4.0
Hyde Park, Mass.	42.2	50.0±	—1±	*4.5
Worcester, Mass.	42.2	49.0	—4	4.5
Sharon, Mass.	42.1	48.0±	—5±	5.0
Springfield, Mass.	42.1	51.6	—5±	5.5
Stoughton, Mass.	42.1	49.0±	—5±	†3.5–5.5

* Depth to top of pipe. † Depth of trench.

TABLE 3.—Continued.

	Lat. Approx.	Temperature.		Depth to Center of Pipe.
		Av. Yearly	Minimum. Extreme.	
Westfield, Mass.	42.1	52.0±	—5±	5.5
Elgin, Ill.	42.0	48.5±	—1±	*6.0
Rockville, Conn.	41.8	49.0±	—2	*4.0
Fall River, Mass.	41.7	49.4	1	4.5–5
New Bedford, Mass.	41.6	49.5±	3	*4.0
East Chicago, Ind.	41.6	51.0±	6±	3.5
Rock Springs, Wyo.	41.5	42.2	—21	*5.0
Norwich, Conn.	41.5	51.0±	2	3.5
Wallingford, Conn.	41.5	51.0	2	4.0
Cleveland, Ohio	41.5	50.0	1	5.2–5.7
Lorain, Ohio	41.5	50.3	12	5.0
Muscatine, Ia.	41.5	50.9±	0±	6.0
Elyria, Ohio	41.4	50.0±	1±	*4.5–5
Oberlin, Ohio	41.3	50.6	12	*5.0
New London, Conn.	41.3	50.7	2	4.0
Bridgeport, Conn.	41.2	51.5	2	*4.0
Williamsport, Penn.	41.2	51.2	1	†5.0
Warren, Ohio	41.2	50.0	10	†5.0
Yonkers, N. Y.	41.0	53.0±	5±	4–4.5
Mauch Chunk, Penn.	40.8	51.0	—5	3.0
Shamokin, Penn.	40.8	49.0±	—17±	*3.0
Woodhaven Water Company, N. Y.	40.7	53.3	5	†3.5
Peoria, Ill.	40.7	51.1	2	*5.0
Burlington, Ia.	40.7	51.5	—3	*5.5
Centerville, Ia.	40.7	49.5±	—9±	4.5
Lima, Ohio	40.7	51.4	—4	5.83
Lewiston, Penn.	40.5	51.0±	—5±	4.0
South Pittsburg, Penn.	40.5	52.8	—3	*3.5
Wilkinsburg, Penn. (Penn W. Co.)	40.5	52.8	—3	*3.5–4.5
Denison, Ohio	40.5	52.0±	—6±	*3.5
New Philadelphia, Penn.	40.5	50.5±	—7±	4.0
Reading, Penn.	40.4	53.6	4	4–4.75
Westmoreland County, Penn.	40.3	52.8±	—3±	*3.5
York, Penn.	40.0	53.0±	1±	*3.0
Springfield, Ohio	40.0	51.5±	—6±	*4.0
Quincy, Ill.	40.0	53.0	0	4.5
Dayton, Ohio	39.6	53.0	—7	*4.5
Marietta, Ohio	39.5	55.2	0	3.0
Mattoon, Ill.	39.5	53.5±	—11	*3.0
Hamilton, Ohio	39.4	54.0±	—3±	5
Baltimore, Md.	39.2	56.0	8	*3.5
Gallipolis, Ohio	38.9	57.0±	—4±	4.5
Belleville, Ill.	38.5	55.5±	5	*3.0

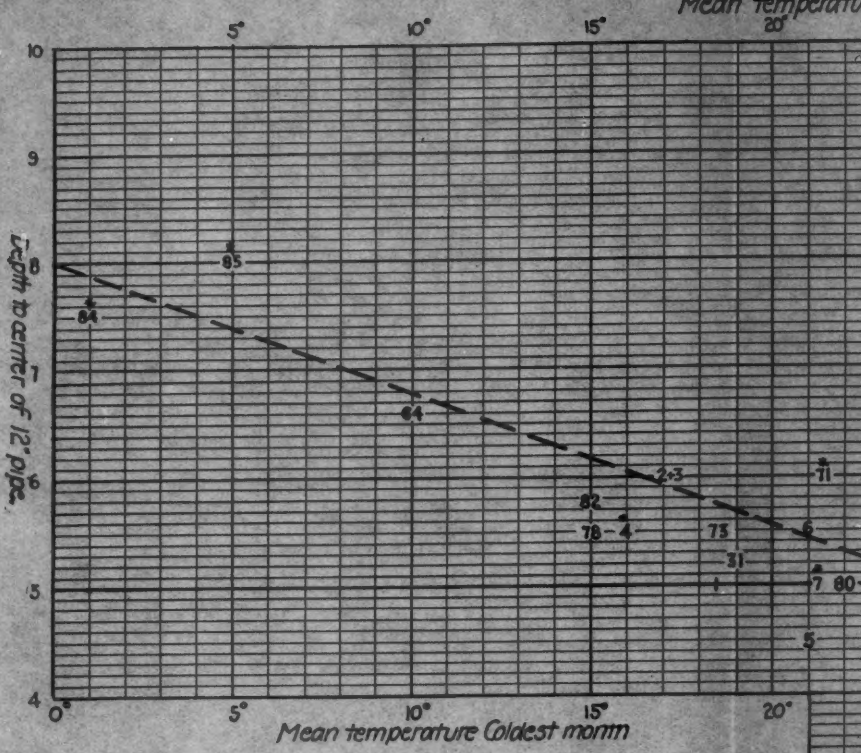
* Depth to top of pipe. † Depth of trench.

in different cities and towns. Presumably this is explainable in most cases by peculiar local conditions; in others, perhaps, by an illogical adaptation of depth to the requirements.

On this diagram a line has been drawn which expresses the relation of depth to mean temperature of coldest month as indicated by an average of the replies received. It will serve to emphasize the variation in depth in cities and towns with the same mean temperature of coldest month, which in the extreme is illustrated by Mauch Chunk, Pa., and Cleveland, Ohio, the former satisfactorily operating pipes at a depth to axis of 3 feet 6 inches, and the latter believing 6 feet 6 inches to be necessary. Obviously local conditions other than temperature, and including depth of snow covering, must furnish, in great part, the explanation. In connection with this diagram, a map, Fig. 2, has been prepared showing the lines of mean temperature of coldest month in the United States.

By reference to Tables 1 and 2 the places represented by the numbers on Fig. 1 can be ascertained. It will be noted that there is quite a marked grouping according to the depth used for pipe of cities and towns located geographically close to one another. The lesser depths employed in those places which appear below the average line are not explained by the use of ground water supplies, as there are as many ground water supplies above the average line as below. Those using shallow depths report practically no trouble, and the question remains whether this immunity results from peculiar local conditions or whether the general practice is unduly conservative. As already stated, it would seem that where there is any velocity of current, depths somewhat less than those indicated by this average line will generally prove sufficient to prevent freezing.

While all cases of freezing reported are stated to have resulted in total stoppage of the pipes, there are records of ice formation in concentric rings in pipes as large as 24 inches in diameter, the occurrences not being evidenced by stoppage of the large main, but only by loss of head through increased friction, or, in some cases, by stoppage of gates or smaller pipe connections by the ice loosening and breaking up in a thaw and forming an ice jam at some point of obstruction. Such formation of ice in a



* Indicates Ground Water supply

Table showing relation of depth of pipe to mean temperature of coldest month in an average year

Latitude at Atlantic Coast corresponding to these temperatures

Temperature	35°	=	Latitude 35° ⊥
"	30°	=	" 41° ⊥
"	25°	=	" 43° ⊥
"	20°	=	" 45° ⊥

FIG

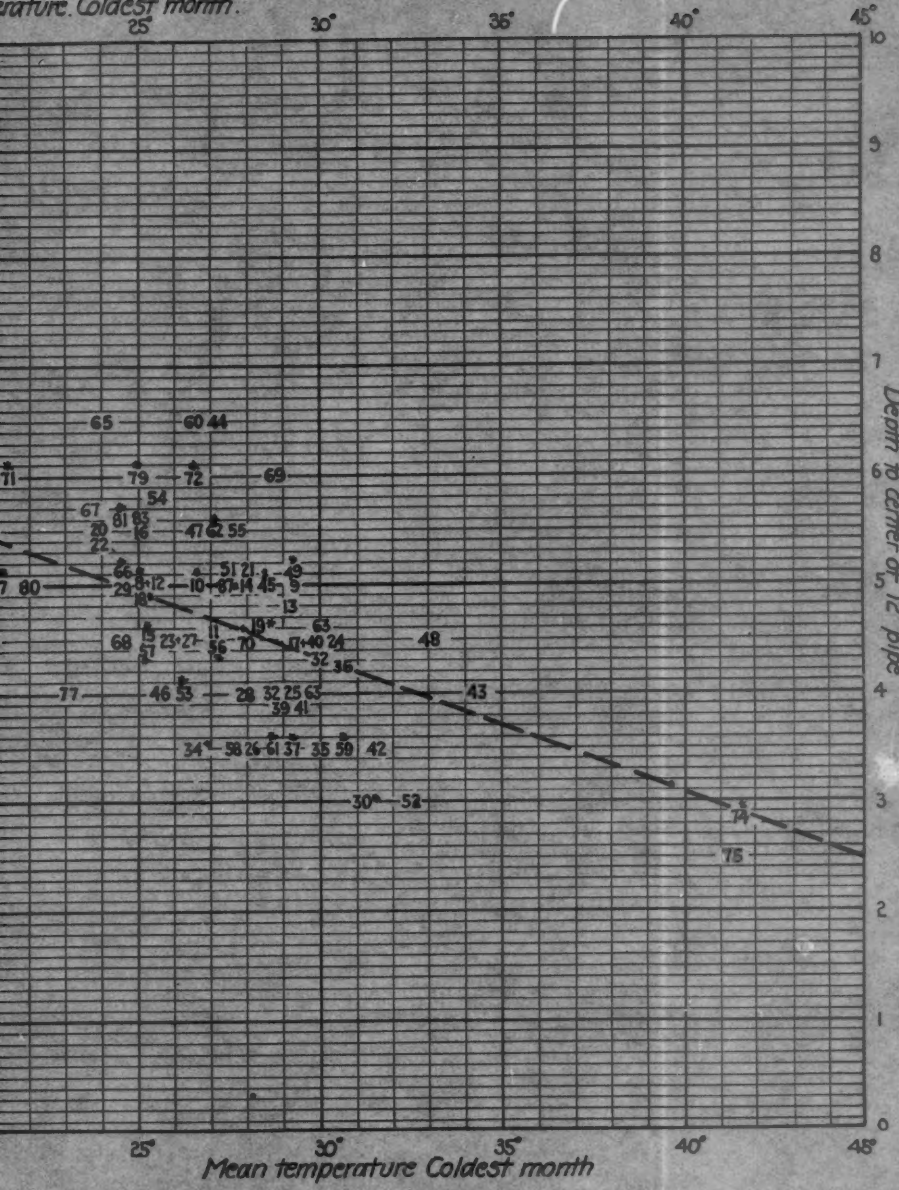
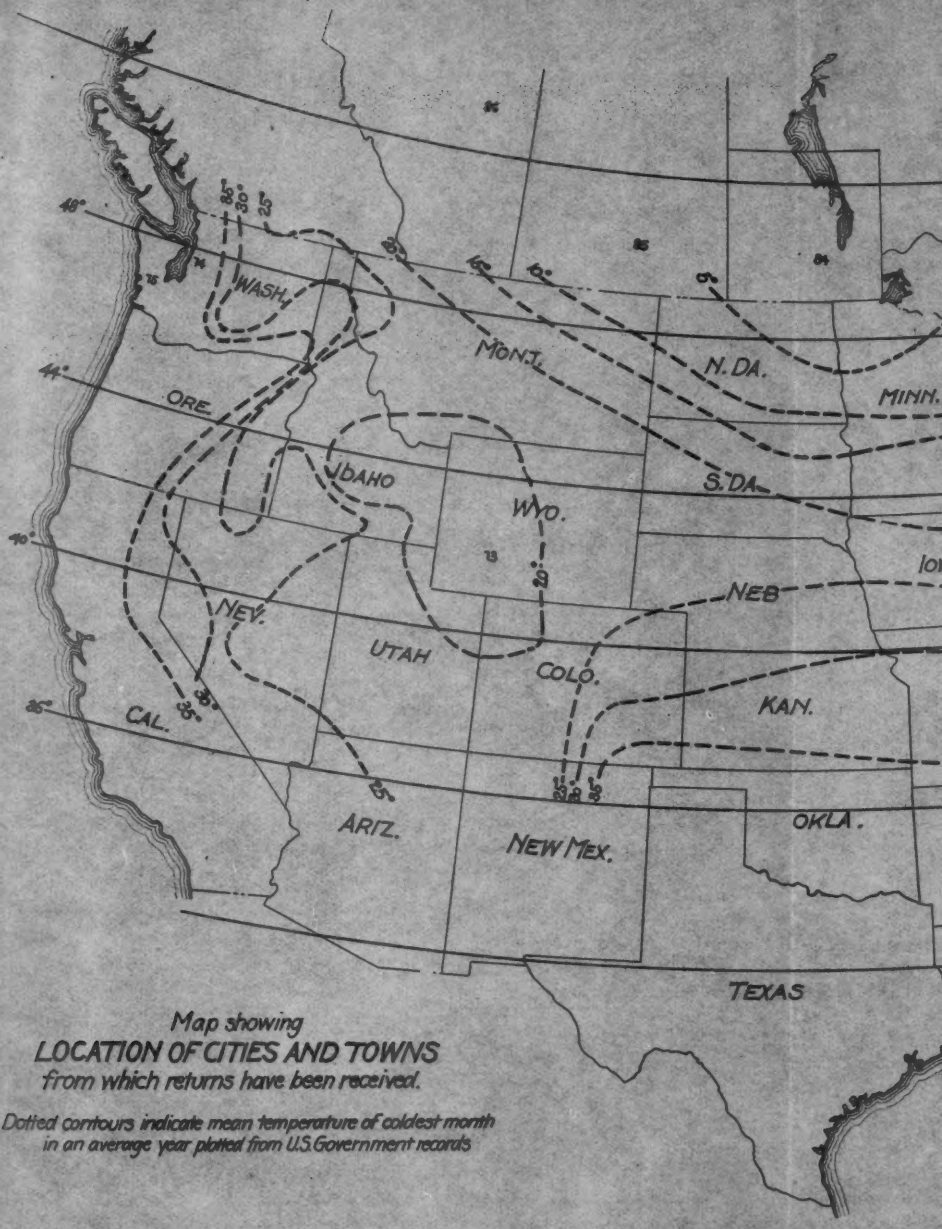

rature. Coldest month.
25°
30°
35°
40°
45°
10
9
8
7
6
5
4
3
2
1
0
Depth to center of 12" pipe
25°
30°
35°
40°
48°
Mean temperature Coldest month

FIG. 1.



Map showing
LOCATION OF CITIES AND TOWNS
from which returns have been received.

Dotted contours indicate mean temperature of coldest month in an average year plotted from U.S. Government records

FIG. 2.

48° Lat.
44° Lat.
40° Lat
36° Lat
ME.
VT.
N.Y.
WISC.
MICH.
IOWA
ILL.
IND
OHIO
PENN.
MD.
W.VA.
VA.
KY.
MO.
TENN.
N.C.
S.C.
ARK.
MISS
ALA.
GA.
LA.
FLA.

3. 2.

layer adjoining the metal of the pipe has occurred in instances of extreme low temperature in the eastern Canadian Provinces in conduits where there was a considerable velocity. Obviously, as the ring of ice forms, the velocity of the water increases and a total stoppage does not result. In other cases of freezing, particularly in smaller pipes, the ice formation is not solid nor does it start from the outside, but is rather in the form of "slush" uniformly distributed throughout the cross-section of the pipe. This has been noted in a 4-inch pipe, in which there was considerable velocity, laid at a depth of 6 feet in a salt marsh in New Brunswick.

There is a belief or tradition in the minds of many plumbers and water-works superintendents that most stoppages by ice formation occur in a thaw which follows a period of severe cold weather, and the reason generally advanced for this alleged phenomenon is that the evaporation from the surface during the early stages of the thaw produces additional refrigeration or reduction of temperature at the depth of the water main sufficient to cause freezing. No indication of the existence of such conditions has appeared in the reports received of frozen pipes, and this reference is here made to induce the production of evidence, if any exists, in support of this theory.

Your committee regrets that the lack of comprehensive response to the circular has made impossible the collection of data sufficient for a more definite and conclusive report.

Yours respectfully,

F. A. Barbour, *Chairman.*
W. C. Hawley.
W. C. Hoad.
Emil Kuichling.
R. S. Lea.
Dabney H. Maury.
R. Winthrop Pratt.

July 19, 1909.

APPENDIX.

(Circular Letter.)

NEW ENGLAND WATER WORKS ASSOCIATION.

BOSTON, MASS., December 30, 1908

Dear Sir: — The undersigned were appointed a committee at the last annual convention of the New England Water Works Association to gather statistics relating to the depth at which water pipes are laid and the resulting experience in freezing. The subject of investigation is important in the possibility that under many conditions pipes are now laid at unnecessary depth.

How valuable the result of the investigation will be depends largely on the response of the men in charge of water-works systems throughout the country, to whom this circular is addressed.

The information desired is of two classes: First, data as to practice in the several cities and towns in the laying of pipes, and a general statement of the conditions which have a controlling influence on freezing. This information will probably be generally negative in character as regards freezing and will prove that, when laid at certain depths, pipes will not freeze. The other class of information is testimony as to experience in actual cases of freezing, with a statement of the controlling conditions. These latter include the size of pipe, depth, character of soil, temperature of air and water, and, last but not least, the velocity of flow in the pipe at the time of freezing.

The committee realize that in order to obtain such information it is necessary to seriously encroach on the courtesy of those to whom this circular is sent out. The results of this investigation will be published and made available to all, and it is the earnest hope of the undersigned that you will generously respond with such information as you possess on the subject.

Yours respectfully,

W. C. HAWLEY,
W. C. HOAD,
EMIL KUICHLING,
R. S. LEA,
DABNEY H. MAURY,
R. WINTHROP PRATT,
F. A. BARBOUR, *Chairman.*
Committee of N. E. W. W. Association.

		Size of Pipe.	Whether Supply Main or Distribution System.	Depth to Axis.	Length of Pipe at this Depth.	Character of Soil.	Whether in Street or Field
	MAINE						
2	Bangor						
3	Brewer	¾"–1"			20	G	S
4	Rumford						
	NEW HAMPSHIRE						
5	Dover	0"–4"	D	4′ 0"	150	G	S
6	Manchester	6"	D	5′ 6"			
7	Nashua						
	MASSACHUSETTS						
8	Billerica	6"	D	6′	200	Large boulders and G	S
9	Boston						
11	Cambridge						
14	Hyde Park	4"	D	4′ 9"	50–75′	G	S
16	Lowell (locks and canals)	8"	D	Pipe exposed under bridge	75′		
17	New Bedford	4", 6", 8"	Always D	One instance, 4′ cover	150′ 4"	G and ashes	S
18	Reading						
19	Sharon	1¼"	D	4′ 0"	341′	Hp	S
13	Fall River	6", 8", 10"	D			G	S
21	Stoughton	6"	D	4′	¼ mile +	C, G	S
22	Westfield	2" and 4"	D			G	S
	CONNECTICUT						
24	Bridgeport	4", 6", 8", 10", 16"	D	3′ 6" to 1′	25 to 150	Varied	S
25	New London						
27	Rockville	6"				G	S
	NEW YORK						
29	Canandaigua	10"	D	42"	100′; about 30′ frozen	Hp	S
87	Rochester						
30	Woodhaven Water Co., New York City						
31	Waterford	8" 6"	D D	4′ 6" 5′	50 100	G Sandy loam	S S
32	Yonkers	4"	D	3′	50	Hp, R	S
	PENNSYLVANIA						
33	Lewiston	4"	D	3′	300	Alluvial	S
34	Mauch Chunk	4"	D	4′	250	Red shale	S
35	Monessen						
36	Reading	6"	D	2′	100	C	S
39	Westmoreland Water Co.						
40	Williamsport	4" and 6"	D	4′ 6"	100–500	G	S
42	York	4" (2 cases)	D	12" and 24"	75	G, C	S
	MARYLAND						
43	Baltimore						
	OHIO						
44	Cleveland	4"	D	4½′–5′	700 500 500 500 } 1885 406 (1904)	Coarse sand mixed with gravel	S
49	Hamilton						
56	Springfield	3"	D	3′ 1½"	600′	C	S
57	Warren	2"	D	3′	50′	C	S
	INDIANA						
58	East Chicago	4"	D	18" to 24"	500′	S	S
	ILLINOIS						
59	Belleville	4"	D	18"	100′	C	S
60	Elgin	6"	D		4 blocks	G mixed	S
61	Mattoon						
62	Peoria	4" 4" 4"	Hyd. br. D D	3′ 6" cover 3′ 0" cover 3′ cover	 250 175	S, G S, G S, G	S S S
	IOWA						
71	Mason City						
72	Muscatine						
	WISCONSIN						
64	Ashland	4"	Hyd. br.	0′ 3"	15′	C	S
	CANADA						
79	Brantford, Ont.						
80	Kingston, Ont.	3" and 4"	D	4′	500′	R	S
81	London, Ont.	4"	D	3′	250′	S	S
82	Pembroke, Ont.	4"	Hyd. br.	5′ 9"	8′	C boulders	S
83	St. Catherines, Ont.	6"	D	4′ 6"		G, S	S
84	Winnepeg, Man.	6" and 8"	D	8′	80′ 6" 10′ 8"	C	S
86	Edmonton, Alberta	4"	S	5′	1 000′	C	S

TABLE 2.—PART I.

PARTICULAR EXPERIENCE IN FREEZING OF PIPES.

	Whether in Street or Field.	Depth of Ground Water at Location of Frozen Pipe.	Depth to Which Ground was Frozen.	Was the Ground Bare of Snow?	Date of Freezing.	Result of Freezing, Whether Total or Partial Stoppage.	If Partial Stoppage, State Thickness of Ring Found Inside Pipe.	Temperature of Air which Resulted in Freezing of Pipe.	Duration of Cold Period.	Did the Low Temperature Described Follow Immediately a Warm, Thawing Period?
	S		6	Nearly	January	Total			Several weeks	Yes
	S			Yes	Winter, 1906	Total		—30°	1906, all winter	Continuous cold
		0	5′ 6″	No	February	Total		0°	Four weeks	No
	S	0	6½′	Yes	Winter, 1905	Total				Warm weather followed discovery
		During the winter of 1903 careful measurements were made of the actual depth to which the frost penetrated. The average depth of frost in 26 different trenches was 4.4′. In all cases the ground was bare.								
	S	Quite deep	5′	Yes	3 years ago	Total				
					Jan., 1895	Total		—2 to +7°	3 days	No
	S	Below pipe	5′	1″ or 2″ of ice	Jan., 1904	Total		25 to —2°	Long period	We notice often that after a thaw has commenced service pipes will be caught by the frost
	S	0	5′	Ground covered except space 8′ x 10′, which happened to come in just the right spot to freeze	Feb., 1904	Total for 5′ or 6′		—0°	5 weeks	No
	S			Yes						
	S	Below except under stream	4′+	Yes, covered with ice	Feb., March, 1905	Total			2 or 3 weeks	
	S	Below pipe	5′	Yes		Total				
	S	Below pipe	Around pipe in each case	Both		Total		0 to 20°	Several days	
	S	0	Have had frost 5′ deep	Yes	Late in Jan.	Total		0° and below	Several days	Steady cold
	S	10′		Yes	March, 1904	Total		Long spell of zero weather	February and March	No
	S	0	5′ 0″	Yes	Jan., 1903	Total		—28°	4 months	No
	S	0	5′ 6″	Yes	Feb., 1903	Total		—28°	4 months	No
	S	0	3′	Yes	1903–'04	Total		10°	6 months	
	S			Yes	Several times previous to 3 years ago	Total				
	S	0	2′ to 2½′	Yes	Jan., 1888	Total			2 months	Yes
	S			No		Total				
	S	10′ ±	5′ or more	No	Jan. and Mar.	Total		Above freezing		Yes, so warm that parties did not anticipate it freezing and had shut off all circulation. Pipes were dead ends
	S	25′ and 10′	32″	Yes	Feb., 1904	Total			11 days	Yes
	S	Below pipe. Probably 20″ below surface	Below pipe	Yes	Feb., 1885 Feb., 1904	Total		Cold wave, 1885, 0 to —15°. 1904, +1 to —8°	3 weeks ±	Yes
	S	Below pipe	3½′	Yes	Feb., 1896	Total		0° and below	3 months	No
	S	Below pipe	3′	Yes	February	Total				
	S	4′	4′	Snow in places	Feb., 1904	Total			Several weeks	No
	S		18″	Yes		Total		15°	Several weeks	
	S	Below pipe	4′ 6″ to 6′ 2″	Ice	Jan., 1895	Total		—20°	20 days	Yes
	S	Below pipe	4	5″ snow	Feb., Mar., '99	Total		—22°	Jan. 22 to Feb 16	No
	S	Below pipe	4	5″ snow	Feb., Mar., '99	Total		—22°	Jan. 22 to Feb. 16	No
	S	Below pipe	4	5″ snow	Feb., Mar., '99	Total		—22°	Jan. 22 to Feb. 16	No
	S		7′	Yes, for 3 months	March, 1901	Total		No unusual change in temperature	The surface of street around hydrant had been bare of snow since early December. No warm period.	
				Yes	Jan. 20, '08	Total		—12°	About 12 days	Yes
	S	6′	4′–6′	No	Feb. 16	Total		—20°		Yes
	S	8′–9′	4′ 6″	No	Jan. 6, '99	Total		—10°	3 to 4 days	Yes; January 4, 49.5°
	S	Below pipe	Below pipe	Yes		Total		—40° ±		No
	S	10′	6′	Yes	Feb., 1888	Total		—22°	Several weeks	Yes
	S	No water in trench, but 8″ sewer crossed trench and exc. froze.	Ground frozen about 6′ down, but frozen earth and snow being put in around pipe froze it	1′ to 3′ snow on ground	Feb. 20, Apr. 21	Total			Nov. 1 to March 30	
	S	Below pipe	6′	No	March 1, '09	Total			The date that this matter was first brought to our notice was March 1, but as there had been a few weeks of cold weather previous to the total freezing, the freezing did not occur altogether on this date, but was caused by the continuous cold weather forcing the frost each day deeper into the ground.	No

		Probable Velocity of Flow through Pipe at Time of Freezing. (Give Rate and Hours of Pumping if a Force Main; Number of People Supplied and Gallons per Capita Consumption if a Gravity Main or Distribution Pipe.)	If You have Any Experience in the Freezing of Stop Valves, State Size and Whether Placed Upright or Horizontal; also Whether Placed in Masonry Vaults.	If You have Any Experience in Ice F Pipe to Standpipe, State Details of Incide of Feed Pipe, and Velocity of Flow in Pi
	MAINE			
2	Bangor		Have had trouble with large valves placed upright not in masonry vaults.	Not any trouble with ice in standpipe.
3	Brewer			
4	Rumford			Our standpipe is on high ground and th from the river, until 4 years ago, we had n houses, and ice 1 or 2′ thick formed arou supply there have been only a few cases of f
	NEW HAMPSHIRE			
5	Dover	Dead end	No	N
6	Manchester	None	No	N
7	Nashua			
	MASSACHUSETTS			
8	Billerica	Dead end	No	No experience since we commenced to su
9	Boston			
11	Cambridge		No	N
14	Hyde Park	No flow		Ice forms in our standpipe every winter.
16	Lowell (locks and canals)	Almost none	No	N
17	New Bedford	Very little, if any. Freezing always in distribution system and in dead ends, with very slight velocity. Never have had a large main freeze.	No	
18	Reading			No vertical riser in standpipe. Inside la ago and was not replaced. No trouble sinc
19	Sharon	None, only 3 houses being on this pipe. Primary cause of freezing was filling of a hole with small stones after pipe was laid in street to within 6″ of the pipe.	No	In 1894–95, during a cold period, ice abou sun came out thawed and fell inside until when it pulled away and broke in sections, tank and pulling 3 or 4 tap bolts through much. The consumption at night being sm hour, giving a good chance to make ice duri top of tank 2′ or more, which indicates a pr
13	Fall River			
21	Stoughton	Dead end	No	N
22	Westfield			
	CONNECTICUT			
24	Bridgeport	Dead ends. Practically no velocity. It is the writer's opinion, based on close observation, that any appreciable velocity will prevent freezing in a water main exposed or buried.		
25	New London			
27	Rockville		No	N
	NEW YORK			
29	Canandaigua	Dead end. 6 services. 1 000 gallons per day	No	
87	Rochester			
30	Woodhaven Water Co., New York City			
31	Waterford	Supplied about 50 people. Dead end	No	Standpipe No. 1 was built with cone-sha running from top angle iron on upper shee casting, cross-braced and all covered with s pipe very heavy. It would settle down a starting pumps would block and jam togeth of ice, in some cases over a ton, would shoo whole jam was forced up. It forced so har caused a rupture at the bottom row of rivet the fifth sheet. I would never put a roof o a way to prevent pack ice from forming ins any kind be placed inside.
32	Yonkers	Dead end		Standpipe enclosed in masonry towers.
	PENNSYLVANIA			
33	Lewiston	Freezing was caused by lack of circulation and was remedied by placing blow-off and opening same during cold weather.		
34	Mauch Chunk	8 families, say 35 people. In digging up the services which started trouble found only 22″ to 24″ top at point in gutter. Primary cause, service freezing and extending into main.	No	
35	Monessen			
36	Reading	Dead end	No	
39	Westmoreland Water Co.		No	
40	Williamsport		No	N
42	York			
	MARYLAND			
43	Baltimore			
	OHIO			
45	Cleveland	Not ascertainable for 1885. For 1904, dead end pipe. Connections were one, 3″; one, 1″; one, ¾″. Probably no flow at end of pipe for few hours at night. Approximate number of persons supplied on line, 120. Consumption per capita, 100 gallons.	February and March, 1904, found that ice had formed inside the domes of two 30″ and two 24″ horizontal valves and one 16″ vertical. These were all valves on connections between mains and had been off. Ice was sufficient to prevent opening until thawed out with steam. 30″ and 24″ valves in brick vaults. 16″ had iron valve box. No trouble with valves that are on.	No
49	Hamilton			
56	Springfield	Dead end	No	No
57	Warren			No
	INDIANA			
58	East Chicago	Possibly 2 500 gallons in 24 hours	No	Have seen ice projecting above top of stan thawed from the sides of the standpipe.
	ILLINOIS			
59	Belleville	Dead end. Two consumers		
60	Elgin	Several feet per minute	Two cases of small ones on dead ends.	We lost our standpipe several years ago getting keyed and remaining in this position it gave way and fell in a mass, causing ruptu
61	Mattoon		Yes, in basements where pipes came in contact with wall of basement above line of outside frost.	
62	Peoria	Little or no velocity Little or no velocity. Dead end		

TABLE 2.—PART II.

in Ice Formation in Standpipe or in Vertical Riser of Incident, with Account of Temperature, Covering ow in Pipes.		Remarks.
dpipe.		
l and the riser is not exposed. When our supply was re had more cases of services freezing and pipes in the ed around riser of standpipe. Since using the ground nses of freezing in services and no ice in standpipe.		
No		
No		
	In the past there have been "freeze ups" on 6" dead ends with shallow covering, say 3½' to 4'. These mains were lowered so as to obtain 5' cover; since then no trouble has occurred. "Freeze ups" occurred on several hydrant branches where the ground was cleared of snow during a long period of low temperature. Our supply, being ground water, with a relatively high temperature at wells and springs, in conjunction with a small reservoir with a capacity of only 33 per cent. greater than the daily consumption, must give our circulation a freshening and warming up that systems having a surface supply and a distribution storage reservoir do not get.	
ed to supply takers in 1809.	Have had service pipes frozen in and around cellar walls. These were put in by contract, the ditches not properly rammed, cellar walls not properly pointed up, or service pipes laid to the required depth. Have laid our own services last 7 years. Cover everything 4½' and have yet to find our first frozen pipe.	
	The water pipes were originally laid 4' deep in Boston. Serious freezing resulted. In 1865 depth increased to 4½' to axis. Serious freezing again resulted on dead ends. In 1892 depth again increased to 5' to axis. No freezing of mains has since taken place.	
No	All of our troubles from freezing have been on supply pipes and those in streets where car tracks are located and the snow removed by the railroad company.	
winter, but we have no damage from it.	Service pipes occasionally freeze up, usually on private land and where not covered as deeply as we cover in streets.	
No	Have used felt, tarred sawdust and hair waste where pipes are exposed or cover shallow.	
nside ladder was broken down by ice about 15 years ble since.		
ce about ½" thick formed on side of tank, which, when e until accumulated mass was about 6' in thickness, ections, carrying away about 30' of iron ladder inside rough the sheet, but otherwise did not damage tank eing small, water in tank will drop only about 12" an ce during a severe cold spell. The ice will show above es a pretty good thickness of ice.		
No		
	Service pipe formerly laid 2½' deep froze cold winters. Mains exposed to air (bridge crossings, etc.) have frozen, but not when water was circulating. Water in tank freezes 4' or 5' deep; water in reservoir, 1' to 2' deep. Frost will run along a pipe for a long distance, and the pipe may be frozen, although the ground around the pipe is not frozen.	
No		
	No main regularly laid at a depth of 4½' to top of pipe has ever been found frozen, and only 3 or 4 cases in all have been found since the establishment of the water works 34 years ago. Hydrant branches have been frequently frozen where for necessary reasons the branches have been laid to less than the normal cover; and even some of the branches at our regular depth have frozen, and would freeze frequently, were the hydrants not regularly inspected and flushed in cold weather. Water mains (8") crossing the Genesee River on highway stone arch bridges have frozen and burst. These mains were laid underneath the sidewalks of the bridges with only 4" or 5" of covering, all that could be obtained. At the time they were repaired they were boxed up and surrounded with charcoal, but as an additional precaution, each winter, a good circulation is maintained by opening a tap in the main at one end of the bridge and allowing the water to run freely and constantly to waste. Some few other cases have occurred of frozen mains at dead ends where there was no circulation and pipe laid at an insufficient depth.	
	Some years ago the grades of streets were cut down in many parts of our territory and mains not lowered in proportion, consequently the next severe winter we had a good many mains freeze and burst. Most of these were less than 2' to bottom of trench and were small (4" and 6"). We had an 8" main within 10" of the surface that did not freeze (distribution main). We used the electric current for thawing out some mains quite successfully at that time. Aside from this winter, after which we lowered mains wherever they had frozen, we have had practically no experience with mains freezing.	
ne-shaped roof made with steel angle iron supports, r sheet to a common center and fastened to a heavy with sheet steel. In 1903 pack ice formed in stand- own at night, when pumps were shut down, and in together. As the pressure forced it up, huge masses shoot up out of the mass with great force until the so hard against the roof structure and braces that it rivets on the fourth sheet from the top and buckled roof on a standpipe in this climate without providing ng inside. Neither should a ladder or projection of	About one half our system is in slate rock, and although laid very shallow we have no trouble from frost in this section. On May 10, 1904, we found a 4" service in a shady place in clay and loam 5' deep frozen and solid full of ice. Do not know how long it had been frozen.	
rs.	Flow in our supply mains constant whether consumption is large or small. For this reason our supply mains in some places are only covered by a foot of ground, and as yet have never had any supply main freeze up.	
	Only four cases of service freezing during the past 8 years. We thaw by electricity and act promptly.	
No		
	Had 150' of 4" distribution pipe wholly exposed from 1900 to 1905 without freezing. The circulation was good. Had a 6" and 8" distribution pipe frozen. Both wholly exposed. Both dead ends owing to closing of valves. Temperature 10° for 4 days, 1903–04.	
	None except on bridges or exposed points. We have places where street grade has been cut, and where our mains have not been lowered, where covering does not exceed from 1' to 2'. If street be paved with fire brick or other suitable material, our experience indicates such is worth a foot of covering.	
No	We lay our mains in a 5' trench in streets, not for fear of their freezing, but to compel services to keep down in streets.	
	Freezing in water mains is not a problem in this climate. It occurs only in extremely cold winters and then only on service pipes where the portion laid by the property owners (from curb cock to house) is laid too shallow. Freezing of mains is very rare and then only small mains in light, loose soil.	
No	On the flats, where ground water is encountered, mains and services are not lowered, provided they are covered with water. Supply mains are not lowered unless they should be found to be less than 2' deep to top of pipe or so shallow as to endanger the valve dome. Distribution pipes are laid at a depth of 6' to top of pipe in order that the service connections and pipes from mains in the street line can be placed at a depth of 6'; otherwise a lesser depth would suffice, provided there is circulation in the pipe system. At a great number of street intersections of pipe, laid prior to 1885, the pipe is only from 4' to 5' deep, and in some cases less than 4' deep. No trouble has ever been experienced on account of these shallow intersections, though no doubt the frost in some cases extended to below the bottom of the pipe. Some mains in outlying districts, acquired by annexation, are only 3½' to 4' deep to top of pipe, in clay ground, and the services are equally as shallow. These mains and services passed through the severe winter of 1903–04 without being frozen, as far as we know. In the outlying districts of the city, especially in the northeastern part, where the ground is not classed as fine sand or sand mixed with gravel, water was encountered 15 or 20 years ago when the mains in these streets were laid. This water was from 3' to 4½' below the surface and generally in a vein of quicksand, which would cause considerable caving if attempt was made to go below it. In such cases the mains were generally laid with only 3½' to 5' cover, or just below the water level. This territory afterward entirely drained, and in such streets the mains and services have to be lowered.	
	We have had (for 10 years) a 10" main crossing one of our river bridges which was exposed and never froze. This pipe has been replaced during summer of 1908 with a 10" pipe for greater capacity. Length of bridge, 550'.	
No		
No		
standpipe 12' to 16' after a warm spell and it had	I have watched the system closely, and when the circulation is poor and the cold weather continued, I would open a hydrant and let it run rather than take the chances of freezing.	
	My experience has led me to believe that mains, as a rule, are laid deeper than they need be. When compelled to lower to grade, we go about 30'. More care should be taken in seeing that services are laid to the proper depth. Plumbers cannot be trusted.	
ago by loose pieces of ice forming on arch and ion until the water lowered, say, 25' to 30', when pture to standpipe.	Relating to freezing, we find the only means of preventing same is to lay all services and other pipe below frost line. During the freezing referred to we used electricity and thawed out pipe and avoided cracking and injury to pipes.	

		was filling of a [illegible] with small stones after pipe was laid in street to within 6″ of the pipe.		In 1894–95, during a cold period, ice about sun came out thawed and fell inside until when it pulled away and broke in sections, tank and pulling 3 or 4 tap bolts through much. The consumption at night being sm hour, giving a good chance to make ice during top of tank 2′ or more, which indicates a pre
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21	Stoughton	Dead end	No	No
23	Westfield			
	CONNECTICUT			
24	Bridgeport	Dead ends. Practically no velocity. It is the writer's opinion, based on close observation, that any appreciable velocity will prevent freezing in a water main exposed or buried.		
25	New London			
27	Rockville		No	No
	NEW YORK			
29	Canandaigua	Dead end. 6 services. 1 000 gallons per day	No	
87	Rochester			
30	Woodhaven Water Co., New York City			
31	Waterford	Supplied about 50 people. Dead end	No	Standpipe No. 1 was built with cone-shap running from top angle iron on upper sheet casting, cross-braced and all covered with sh pipe very heavy. It would settle down at starting pumps would block and jam together of ice, in some cases over a ton, would shoot whole jam was forced up. It forced so hard caused a rupture at the bottom row of rivets the fifth sheet. I would never put a roof on a way to prevent pack ice from forming insid any kind be placed inside.
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	PENNSYLVANIA			
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34	Mauch Chunk	8 families, say 35 people. In digging up the services which started trouble found only 22″ to 24″ top at point in gutter. Primary cause, service freezing and extending into main.	No	N
35	Monessen			
36	Reading	Dead end	No	
39	Westmoreland Water Co.		No	
40	Williamsport		No	No
42	York			
	MARYLAND			
43	Baltimore			
	OHIO			
44	Cleveland	Not ascertainable for 1885. For 1904, dead end pipe. Connections were one, 3″; one, 1″; one, ¾″. Probably no flow at end of pipe for few hours at night. Approximate number of persons supplied on line, 120. Consumption per capita, 100 gallons.	February and March, 1904, found that ice had formed inside the domes of two 30″ and two 24″ horizontal valves and one 16″ vertical. These were all valves on connections between mains and had been off. Ice was sufficient to prevent opening until thawed out with steam. 30″ and 24″ valves in brick vaults. 16″ had iron valve box. No trouble with valves that are on.	No
49	Hamilton			
56	Springfield	Dead end	No	No
57	Warren			No
	INDIANA			
58	East Chicago	Possibly 2 500 gallons in 24 hours	No	Have seen ice projecting above top of stand thawed from the sides of the standpipe.
	ILLINOIS			
59	Belleville	Dead end. Two consumers		
60	Elgin	Several feet per minute	Two cases of small ones on dead ends.	We lost our standpipe several years ago getting keyed and remaining in this position u it gave way and fell in a mass, causing rupture
61	Mattoon		Yes, in basements where pipes came in contact with wall of basement above line of outside frost.	
62	Peoria	Little or no velocity Little or no velocity. Dead end Little or no velocity		
	IOWA			
71	Mason City			
72	Muscatine			The temperature of our ground water is abo reservoir in the coldest weather.
	WISCONSIN			
64	Ashland			
	CANADA			
79	Brantford, Ont.	No flow, or it would not have frosen	No	
80	Kingston, Ont.	Forty dwellings. Consumption, 100 gallons per capita	One 16″ valve upright in plank box froze stuffing box only.	Ice forms in standpipe 2′ thick on sides trouble, as it is always moving up or down. Temperature of water, 40°.
81	London, Ont.	Dead end. No flow		
82	Pembroke, Ont.		No. All in masonry vaults placed upright	Standpipe is open and freezes every year; ab moving up and down with rise and fall of wate
83	St. Catherines, Ont.	Very light	One 20″ upright last winter 18″ deep in rock bursting upper body. Now has cover 6″ deep, making double air space, which will prevent freezing.	
84	Winnepeg, Man.	Dead end. No flow		
86	Edmonton, Alberta	Practically no velocity	No	We have here a standpipe, 600 000 gallon poses, and, therefore, acting only as a cushion heated every day during winter by a coal stov frost.

e about 4″ thick formed on side of tank, which, when until accumulated mass was about 6′ in thickness, tions, carrying away about 30′ of iron ladder inside ough the sheet, but otherwise did not damage tank ng small, water in tank will drop only about 12″ an during a severe cold spell. The ice will show above s a pretty good thickness of ice.	
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No	
No	
standpipe 12′ to 16′ after a warm spell and it had	I have watched the system closely, and when the circulation is poor and the cold weather continued, I would open a hydrant and let it run rather than take the chances of freezing.
	My experience has led me to believe that mains, as a rule, are laid deeper than they need be. When compelled to lower to grade, we go about 30′. More care should be taken in seeing that services are laid to the proper depth. Plumbers cannot be trusted.
ago by loose pieces of ice forming on arch and tion until the water lowered, say, 25′ to 30′, when upture to standpipe.	Relating to freezing, we find the only means of preventing same is to lay all services and other pipe below frost line. During the freezing referred to we used electricity and thawed out pipe and avoided cracking and injury to pipes.
	The trouble we had in February, 1905, was on dead ends, mostly where there was no circulation and little water used, and in most cases mains were not down the required depth, but the trouble was remedied by connecting these mains to make circulation. The ground was entirely bare, no snow or ice. We had to renew 750′ of pipe. We had no hydrants or gate valves frozen.
is about 50°. We have not had any ice on our	Our greatest trouble is in the spring of the year when the frost is leaving the upper section or top of the ground and all shallow service pipe becomes frozen. The frost seems to go down on the bottom when it is leaving on top, but this only lasts, say, about two weeks at the most. We have had no trouble in our mains on this account.
	While it is our rule to lay all pipes with a depth of cover of 6′, we now have many mains that have a cover of about 5′, and in places on one line of 16″ main the cover is as small as 3′, due to the grading down of the street surface since the mains were laid. But in my 15 years' connection with the plant there has never been a single instance of a supply or distribution main freezing, although I have seen cases where the 16″ main had the surrounding soil frozen entirely around it. In all instances of frozen service connections it has been due to a grading down of the street subsequent to the laying of the service pipe and when the snow has blown off the ground or was packed hard from continuous travel. Our water as it comes to the pumps has a uniform temperature of 34° F. from the time the lake freezes early in December until the ice leaves it about April 20.
	We have been careful to put the pipes deep enough to protect them from frost, and this would not have happened only for change in grade of street. Some 11 years ago we had a branch to a fire hydrant frozen from practically same cause. The street was bare, no snow, ground wet, and they stripped 2′ off face of street, leaving only 3′ to 3½′ covering. Another froze up tight, being a dead end.
ides and 1′ thick on surface, but has given no down. Pipe enters at bottom, where it is safe.	I find that frost very often seems to go farther down after a low temperature in February and March, and very often services would freeze at that time, but the real reason may be that consumers let the water run all night in cold weather and not during mild weather. It is certainly better to lay all mains and services where they will be safe under all conditions. In rock trenches we cart away all rough stone and fill trench with clay to within 1′ of the top, then put on fine broken stone. The cases of freezing recorded were 20 years ago, and all mains which froze were relaid and have given no trouble since. We had 4 mains frozen at 4′ deep, our intake then being near the shore and taking water at 10′ deep and 34° F. The intake is now ½ mile from shore, taking water at 32′ deep and 40° F.
	Street had been graded down.
ar; about 1′ of ice forms around the side 20′ long, f water.	
	During the severe winter of 1904–05, while digging out some burst service pipes (frozen) in a soil where stony gravel predominated, we found frost in the dry gravel 7′ 0″ below surface, but owing to strong circulation in mains at those points had no mains frozen or hydrant branches, frequent testing of latter during danger period being made. The case of freezing referred to occurred on system just completed that fall, trenches being wetted and rammed in back-filling, followed by continued severe weather.
gallons capacity, not sufficient for reservoir pur- ushion valve to our pumps. This tank is kept al stove and no trouble has been experienced by	With reference to the case of water main freezing, as mentioned, I may say that this was a 4″ supply main running from the city level over a hill to a large mill situated on the flats below the city. As this main has a circuit formed by the connection being made around a triangular block of land, there should be a certain amount of velocity in the pipe, but as the mill was then drawing no water, the water was practically lying still in the pipe. On the line between the top of the hill and mill there are two or three 1″ services. At point of freezing for about 1 000′ the pipe is only covered with 5′ of earth. We tried to thaw out pipe by an electric thawing machine, but were unsuccessful. We then opened the ground and by cutting the pipe thawed it out from a steam boiler.

December 30, 1908.

(CIRCULAR.)

NEW ENGLAND WATER WORKS ASSOCIATION.

Statistics Relating to Depth of Laying Water Pipe.

Kindly fill in and return this data to FRANK A. BARBOUR, Chairman Committee on Depth of Laying Water Pipe, 1120 Tremont Building, Boston, Mass.

Date of reply....., *Name*....., *Official position*.....

..... *Water Works, City or Town*..... *State*.....

{ Municipal or Company Works. }
{ Give name if latter. }

GENERAL DATA.

1. *Temperatures.*
   Mean yearly temperature, degrees F.
   Mean temperature, coldest month.
   Extreme minimum temperature and date of occurrence.
   Minimum temperature at source of supply and date of observation.
2. *Location of City.*
   Distance from ocean.
   Elevation above sea level.
3. *Source of Supply.* (Surface or ground water.)
4. *Method of Distribution.* (Gravity or pumping.)
5. *Elevated Storage with Pumping System.* (Whether reservoir or standpipe.)
   Size and depth of reservoir or standpipe.
   Reservoir or standpipe open or covered.
6. *Capacity of Reservoir or Standpipe in Relation to Daily Consumption.*
7. *Hours of Pumping Daily in Period of Minimum Temperature.*
8. *Approximate Hourly Rate of Pumping during Winter Months.*
9. *Does Pumping Entirely Cease at Night during Coldest Weather? If Not, Give Minimum Hourly Pumping Rate.*
10. *Size of Supply Main, either Gravity or Pumping.*
    If supply is by gravity, state whether delivery is practically uniform or whether it is variable.
    If variable, give the minimum rate and number of hours.
11. *Character of Soil.* (State whether rock, hardpan, clay, sand, gravel, or alluvial.)
12. *General Depth of Ground Water.*
    In route of supply main.
    In distribution system.
13. *Depth to which Frost Extends in Streets.*
    Average depth.
    Maximum depth in gravel.
    Maximum depth in clay.
    Maximum depth in sand.

14. *Depth to which Frost Extends in Fields.*
    Average depth.
    Maximum depth in gravel.
    Maximum depth in clay.
    Maximum depth in sand.
15. *Average Snow Covering.*
    In streets.
    In fields.
16. *Is Ground likely to be entirely Free from Snow during Days or Weeks of Coldest Weather?*
17. *Depths at which Pipes are Laid.*
    Supply Mains. (If depths are changed in soils of different character, specify.)
    Diameters. (Depth to axis of pipe.)
    In streets.
    In fields.
    Distribution system.
    Diameters. (Depth to axis of pipe.)
    In streets.
    In fields.
    Do you take into account the effect of different pavements in streets?
18. *Service Connections.*
    Character. (Describe method of connection with main, whether tapped on top or side.)
    Size.
    Depth.
19. *Hydrant Branches.*
    Size.
    Depth.
    Average length.
20. *Hydrants.* (State method of providing for drainage.)
21. *Number of Cases of Freezing Yearly*
    In mains.
    In services.
22. *Are the Depths of Pipe, in your judgment, generally Sufficient, except under Extreme Conditions of Temperature?*
23. *Do these Unusual Conditions Occur with Sufficient Frequency to justify a General Lowering of the Pipe System?*

Particular Experience in Freezing with Pipes.

If you have had any experience in the freezing of pipes, state details as follows:

Size of pipe.
Whether supply main or distribution.
Depth of axis.

Length of pipe at this depth.
Character of soil.
Whether in street or field.
Depth of ground water at location of frozen pipe.
Depth to which ground was frozen.
Was the ground bare of snow?
Date of freezing.
Result of freezing, whether total or partial stoppage.
If partial stoppage, state thickness of ring of ice found inside the pipe.
Temperature of air which resulted in freezing of pipe.
Duration of cold period.
Did the low temperature described follow immediately a warm, thawing period?
Probable velocity of flow through pipe at time of freezing. (Give rate and hours of pumping if a force main; number of people supplied and gallons per capita of consumption if a gravity main or distribution pipe.)

If you have any experience in the freezing of stop valves, state size and whether placed upright or horizontal; also whether placed in masonry vaults.

If you have any experience in ice formation in standpipe or in vertical riser pipe to standpipe, state details of incident with account of temperatures, covering of feed pipe, and velocity of flow in pipes.

Remarks.

DISCUSSION.

MR. F. A. BARBOUR.* I may say that whatever of value there is in this report, aside from the statistical value, is largely comprehended in the diagram (Fig. 1) indicating the relation between depths at which pipe is laid and the mean temperature of the coldest month in the average year in different parts of the country. This diagram covers a variation of mean temperature from zero to 45°. One city in Canada is shown with a mean temperature of coldest month of zero and pipes laid at a depth of 8 feet. At the other extreme appear places with a mean temperature of coldest month of 40° and the pipes laid at a depth of 3 feet. The returns from various cities and towns have been plotted and a line representing the average relation of depth to the mean temperature of coldest month has been drawn.

It is interesting to note that from the information received there are no more cases of freezing in those places where the depth of the pipe is less than in those where the depth is greater

* Boston, Mass. (Chairman of the Committee on Depth of Water Pipe.)

than that shown by the average line. It must, therefore, be concluded either that this variation in the depths at which pipes are laid in different localities with the same mean temperature of coldest month are to be explained by peculiar local conditions, or that in some places the depth shown is unnecessarily great. Personally, the speaker believes that it is safe to lay pipes where there is an assured circulation at all times, at depths less than are frequently adopted in present practice.

MR. LEONARD METCALF.* Mr. President, it seems to me that the Association is to be congratulated upon this excellent report of Mr. Barbour's committee. I think many of us recognized that any inquiry of this sort was bound to give negative results, for the most part, but it certainly gives us a good record for what current practice is, and I think it brings home to all of us the desirability of following up carefully any cases of frozen pipes that we as individuals may have. The freezing of pipes seems to depend, as would be expected, more on the velocity through the pipe than anything else, and it is on that very fact that we have the fewest data, as it is very difficult to get information of that sort. It is to be hoped that we may hereafter have some experience discussions before the Association, when members who have had recent cases of frozen pipes will tell us about their troubles.

MR. R. C. P. COGGESHALL.† I don't know what has been the experience of others, but Mr. Barbour touched on one thing in the report that we have noticed several times, and that is that when a thaw comes after a long period of cold weather, when there have been some services frozen, other service pipes in the immediate vicinity will catch or stop. I have always been puzzled about it, and have thought there was a good deal of moonshine in the idea, but still the facts seem to indicate that there is something in it, and Mr. Barbour's explanation is very interesting to me. I should like to know if others have had this same experience.

MR. GEORGE A. STACY.‡ Mr. President, we had a small main that we laid through rock during the late fall, and the back filling, perhaps, was a little rougher than it would have been if there

* Of Metcalf & Eddy, Boston, Mass.
† Superintendent Water Works, New Bedford, Mass.
‡ Superintendent Water Works, Marlboro, Mass.

hadn't been frost in the ground. It was practically at a dead end, as there was hardly any circulation beyond at that time, although there were houses building. In the spring there was a stoppage in the pipe, and it was on a day when the water was running in the streets and you could go around in your shirt sleeves with comfort. We located the stoppage by the hydrant connections near this ledge. I noticed that the water was running down in places between the stones of the back filling which had been done in the fall, but in a very small stream. As it was then in the middle of the afternoon we made provision to allow everything to remain as it was so as not to have to work all night, for there wasn't enough to do to warrant that expense, and we could make other arrangements that would be a good deal cheaper. We expected to bring up the work gang in the morning and tackle the job, thinking that if the water could run down through the rock we wouldn't have much trouble in getting down to the pipe. The next morning, however, when we went down there with the gang, everything was all right; it had thawed out itself. The only reason I could give for it in this case was the state of the weather, the open condition of the back filling as it settled, and the action of the high temperature that day and the refrigeration, or action of that nature, causing the water in the pipe to freeze, as there was scarcely any circulation there at all. We never had any trouble at that place afterwards, and that was quite a few years ago.

MR. CHARLES W. SHERMAN.* The fact stated by Mr. Barbour that he has had no reports of pipes larger than 10 inches in diameter which have frozen, and very few pipes larger than 6 inches in diameter, would seem to suggest the possibility, at least, that pipes of the larger sizes might to a greater extent than is now the practice be advantageously laid at a lesser depth than the smaller pipes.

MR. JOHN H. FLYNN.† I have had a 36-inch pipe freeze and burst, and still not be frozen solid. It was laid on a trestle over a river, 600 feet or more of pipe, and 12 lengths split the whole length, and they were not frozen solid. I don't know whether anybody else ever had any such experience.

* Principal Assistant Engineer, Metcalf & Eddy, Boston.
† Boston, Mass.

PROCEEDINGS.

November Meeting.

Hotel Brunswick,
Boston, November 10, 1909.

The November meeting of the Association was held at the Hotel Brunswick, Boston, on Wednesday, November 10, 1909.

President Robert J. Thomas presided.

The following members and guests were present:

Members.

M. N. Baker, C. H. Baldwin, A. F. Ballou, L. M. Bancroft, T. H. Barnes, H. K. Barrows, J. F. Bigelow, A. E. Blackmer, E. C. Brooks, A. W. F. Brown, James Burnie, George Cassell, J. C. Chase, J. H. Child, C. E. Childs, H. W. Clark, W. F. Codd, R. C. P. Coggeshall, M. F. Collins, J. H. Cook, J. W. Crawford, G. E. Crowell, G. E. Cutting, Jr., A. O. Doane, G. H. Finneran, J. H. Flynn, A. N. French, F. J. Gifford, C. W. Gilbert, T. C. Gleason, A. S. Glover, F. H. Gunther, R. K. Hale, F. E. Hall, F. C. Hersey, Jr., J. L. Howard, W. S. Johnson, E. W. Kent, Willard Kent, G. A. Kimball, G. A. King, J. J. Kirkpatrick, N. A. McMillen, D. E. Makepeace, A. E. Martin, John Martin, John Mayo, Leonard Metcalf, William Naylor, T. W. Norcross, F. L. Northrop, E. M. Peck, T. A. Peirce, W. H. Richards, Charles Saville, A. L. Sawyer, W. H. Sears, E. M. Shedd, C. W. Sherman, H. O. Smith, G. H. Snell, G. A. Stacy, T. V. Sullivan, W. F. Sullivan, R. E. Tarbett, R. J. Thomas, W. H. Thomas, L. D. Thorpe, D. N. Tower, W. H. Vaughn, J. C. Whitney, G. E. Winslow. — 72.

Associates.

Anderson Coupling Company, by C. E. Pratt; Ashton Valve Company, by C. W. Houghton; Harold L. Bond Company, by Harold L. Bond; Builders Iron Foundry, by A. B. Coulters and F. N. Connett; Chapman Valve Mfg. Co., by Edward F. Hughes; Darling Pump and Manufacturing Company, by Herman H. Davis; F. H. Hayes Machinery Company, by F. H. Hayes; Hersey Manufacturing Company, by H. D. Winton, A. S. Glover, and W. A. Hersey; International Steam Pump Co., by Samuel Harrison; Ludlow Valve Manufacturing Company, by H. F. Gould; Charles Millar & Son Company, by Charles F. Glavin; H. Mueller, Manufacturing Company, by George A. Caldwell; National Meter Company, by H. L. Weston, J. G. Lufkin

and C. H. Baldwin; Neptune Meter Company, by H. H. Kinsey; Norwood Engineering Company, by H. W. Hosford; Pittsburg Meter Company, by F. L. Northrop; Rensselaer Manufacturing Company, by Fred S. Bates and C. L. Brown; Ross Valve Manufacturing Company, by William Ross; A. P. Smith, Manufacturing Company, by F. N. Whitcomb; Thomson Meter Company, by E. M. Shedd; United States Cast Iron Pipe and Foundry Company, by Frank E. Nevins; Waldo Brothers, by H. E. Browne; R. D. Wood & Co., by W. F. Woodburn. — 29.

GUESTS.

Messrs. Frank S. Baily, W. E. Hannan, Fred S. Gore, and Joseph Weeks, Boston, Mass.; James J. Kirby, Fall River, Mass.; James T. Davidson, Lawrence, Mass.; Walter Beals, Middleboro, Mass.; William F. Williams, New Bedford, Mass.; Percy Warren, Weston, Mass.; John C. Hoyt, Washington, D. C. — 10.

A communication was received from the Boston Society of Civil Engineers inviting members of the Association to attend a lecture in the evening by T. Howard Barnes, engineer of the United Fruit Company, on "Engineering Works, People, and Conditions in Central America."

The following names of applicants for active membership were read by the secretary: Herbert H. Barnes, Hotel Brunswick, Boston, Mass., president of the Hartford, Vt., Water Company; Percy Warren, Weston, Mass., superintendent of Weston Water Company; Guy C. Emerson, Boston, Mass., superintendent of streets, Boston; D. G. Thomas, Denver, Colo., chief engineer of the Denver Union Water Company; Walter L. Beals, Middleboro, Mass., clerk Middleboro Water Works; Lyman P. Thomas, Middleboro, Mass., civil engineer.

On motion of Mr. Collins, the Secretary was directed to cast the ballot of the Association in favor of the candidates named, and he having done so, they were declared elected.

The President read the following letter:

BILLERICA WATER WORKS.
OFFICE OF WATER COMMISSIONERS.

NORTH BILLERICA, MASS., October 29, 1909.

TO THE EDITOR
NEW ENGLAND WATER WORKS ASSOCIATION,
14 Beacon Street, Boston:

Dear Sir, — As a matter of special information to the writer, and of general interest to many readers of your magazine, I would like to suggest the collection

and publication of information as to the conditions under which extensions of water mains are made by town-owned water supplies.

In going through the files of the JOURNAL I find only meager references to this matter, and my idea would be to cover the following points, and such others as you may think pertinent:

1. Are extensions made by vote of town or controlled by water commissioners?
2. Is a guaranteed revenue required before putting in extensions, and if so, what per cent. on cost, and what items, are included in said cost?
3. If a guarantee is required and is provided for by town by-law, quote latter.
4. Quote the form of guarantee.

If the suggestion seems practicable, the sooner it is taken up, the greater value the information obtained would be, as matters in this relation come up at many of the spring annual meetings.

Yours truly,

(Signed) JOSEPH F. TALBOT,
Chairman Water Commissioners.

THE PRESIDENT. The Executive Committee has voted to recommend the appointment of a special committee of five to take up the matter referred to in Mr. Talbot's letter and report on it later.

On motion of Mr. Sullivan, of Nashua, it was voted to accept and adopt the recommendation of the Executive Committee.

The President subsequently appointed the following committee: Messrs. Charles W. Sherman, Edwin C. Brooks, A. W. F. Brown, George H. Robertson, and Norman McMillen.

THE PRESIDENT. The Executive Committee passed a vote to-day instructing the Secretary to send out postal cards to all the members, requesting them to forward suggestions as to the place for holding the next annual meeting in September, 1910. The committee believe that we ought to take action upon this matter earlier than we have sometimes in the past, and would like the advice of the members. We hope that replies will be sent in so that the result can be reported at the next meeting, December 8.

MR. WILLIAM H. THOMAS.* Mr. President, unless the committee suggests some names, I think you will get quite a wild sort of a return. I suggest that a list of places be offered to the members to select from. I might say, for instance, that I would like to go to New Haven, but perhaps there would be no accom-

* Superintendent Water Co., Hingham, Mass.

modations there for us. The committee knows where the accommodations are, and many of us do not. It seems to me, therefore, that if a certain number of places were suggested by the committee it would, perhaps, bring the matter to a head better.

THE PRESIDENT. That was mentioned at the meeting, but it was urged that the suggestions the members might make would be simply advisory; there would be nothing final about it. We thought we would get the sentiment of the members and afterwards, of course, we would use our own judgment in the matter. [Laughter.] We want to give you all an opportunity to be heard, anyway. Is there anything else to be called to our attention before we proceed with the regular program of the afternoon?

MR. EDWIN C. BROOKS.* Mr. President, a little "experience" might be of interest to some of you good people who are running a Smith tapping machine. It isn't very often that a sleeve furnished with a Smith tapping machine is defective, but such a thing does occur once in a while, as I recently found out.

In making a cut on a 20-inch main that was rather old, and the gates not too tight, after the hole was drilled through, but before the cutter began to work, the pressure of water showed a defect in the sleeve that would not permit of using it; consequently, the next thing to do was to remove the sleeve. An inch hole in the side of a 20-inch pipe is not a pleasant thing to encounter in a ditch, and in order to get around the trouble we pulled the tools back, shut down the gate, and then removed the cutter-bar, taking off the cutter-head and the drill. Into the socket where the drill fits we put a pine plug, whittled to about the size of the drill or a little larger, and, putting the machine together, we screwed the pine plug into the hole. The thing was perfectly tight, so that we could take off the sleeve and substitute another portion without the interference with the water that we should have had if we had attempted to make the repair in any other way. I thought perhaps some of you might get into a similar difficulty some time, and if you happened to hear of this it might save you a little bother.

The President then called on Mr. William S. Johnson, sanitary and hydraulic engineer, Boston, Mass., who read a paper on

* Superintendent of Water Works, Cambridge, Mass.

"Ground Waters as Sources of Public Water Supplies." The paper was discussed by Mr. Lewis D. Thorpe, Mr. A. O. Doane, Mr. George E. Winslow, Mr. John H. Flynn, Mr. Harold K. Barrows, Mr. William S. Sullivan, Mr. Robert S. Weston, Mr. Harry W. Clark, Mr. M. N. Baker, Mr. M. F. Collins, and Mr. George A. Stacy.

The President announced that, owing to the illness of Mr. Frank A. Barbour, chairman of the "committee to gather statistics relative to the depth at which water pipes are laid, and the resulting experience with frozen pipes," the presentation of this report would be deferred until the next meeting.

Mr. Harvey S. Chase's paper on "Water Works Accounting" was also postponed.

The report of the committee "to prepare a standard specification for fire hydrants" was called for.

MR. WILLIAM F. SULLIVAN. I know that Mr. Lacount, the chairman of this committee, is not ready to present the report to-day. There have been several meetings of the committee in which we have gone over the matter, but Mr. Lacount is doing the bulk of the work, and is compiling specifications which we hope will meet the approval of the Association. He has invited the manufacturers, as well as water-works men, to participate, and before the next meeting he expects to have the specifications in their third draft in shape so that advance copies can be sent to all the members. Mr. Lacount's intention is that there shall be a full and free discussion of this hydrant question before the Association, so that we may get all the suggestions and the amendments necessary, so that the final specifications may be put in a form which will meet the demands and the approval of the members.

We had a meeting to-day, and Mr. Lacount recommended a conference with the National Protective Fire Association, who are working along similar lines, and I know that at the next meeting Mr. Lacount will probably be here with all the information and data which he has been preparing for many months, and be ready to present it.

THE PRESIDENT. Has Mr. Stacy anything to say on the report or about the committee?

MR. GEORGE A. STACY. There is nothing to say, Mr. President, except that I hope the Association will have patience with us.

We shall be on the firing line at the next meeting, I expect, and we shall be pleased to have you find all the fault you can with what we have done, and we will welcome any suggestions you may make. The committee, as a whole, has met only twice to do much work; once, a week or so ago, and again to-day; but we have made considerable progress in getting together what I hope will result in specifications which will be satisfactory, as near as it is possible to make such things satisfactory, to all concerned, including the superintendents, those who are responsible for the action of the hydrants, and the builders.

Of course, this is a pretty large problem. We do not suppose we are going to satisfy everybody, but we do hope we are going to make a satisfactory start, so that we will have some standard to work on. At present, when we are ordering hydrants, we really don't know what we are going to get. There is nothing in the way of any exact specifications; nothing but a general statement of a hydrant. When you go into the market to buy one, you don't know whether you are going to get a 4-inch gate or a 3-inch gate or a 5-inch gate; a 4-inch base or a 5½-inch base; whether there is going to be a bronze screw or not, or whether machine work is going to be done in the foundry, or whether it is going to be done in a machine shop where it should be done.

It seems to me that the manufacturers are not making these hydrants according to their own ideas; they make just what we demand. If we demand good hydrants and put our demands in such a shape that all manufacturers have to bid on the same basis, we shall get good hydrants. If we allow the manufacturers to build hydrants in the foundry instead of the machine shop, we will get foundry hydrants; and if any of you like that kind, why, all right; but I would rather pay a little more and have the work done in the machine shop, and get less sand in the joints and stuffing boxes than some of the hydrants have to-day. I don't mean to cast any slur upon the hydrant makers; it is our own fault that we don't demand better things. When we do make such demand, they will do anything we are ready to pay for, and we ought to be willing to pay for anything that is good, because we can't get it in any other way.

On motion of Mr. M. F. Collins, adjourned.

EXECUTIVE COMMITTEE.

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Wednesday, November 10, 1909.

Present: President Robert J. Thomas and members Richard K. Hale, George A. King, Ermon M. Peck, Charles W. Sherman, Lewis M. Bancroft, George A. Stacy, and Willard Kent.

Six applications were received and the following applicants were recommended for membership, viz.:

Lyman P. Thomas, superintendent water works, Middleboro, Mass.; Walter L. Beals, clerk Middleboro Water Works, Middleboro, Mass.; Guy C. Emerson, superintendent of streets, Boston, Mass.; Percy Warren, superintendent Water Company, Weston, Mass.; Herbert H. Barnes, president Hartford, Vt., Water Company, Boston, Mass.

Voted: That the Executive Committee recommend to the Association that a committee be appointed for the collection and publication of information as to the condition under which extensions of water mains are made by town-owned water supplies.

Voted: That the Secretary be authorized to send to the members of the Association postal cards requesting suggestions as to place of holding the next annual convention, and asking that replies be returned before December 1, next.

Adjourned.

WILLARD KENT, *Secretary.*

OBITUARY.

JOSEPH E. BEALS died at his home in Middleboro on September 3, 1909. Mr. Beals was born in Middleboro March 18, 1834. He was the only son of Ebner and Lucy Beals. In 1862 he entered the employ of Albert Alden, proprietor of the Bay State Works, where he remained for thirty years, when ill health forced him to retire. After this, Mr. Beals devoted himself to work of a public nature. He has been secretary and treasurer of the Board of Trustees of the Public Library, and a member of the Water Board since the construction of the works, acting also as chief clerk and superintendent. In 1906 he was elected a representative to the legislature. Mr. Beal's first wife was Mary E. Leonard, of Bridgewater. In 1876 he married Harriet C. Bardin. Mr. Beals was a vice-president of the New England Water Works Association in 1904 and was senior editor of the JOURNAL from 1897 to 1900.

Mr. Beals was elected a member of the Association on June 16, 1886.

ADOLPHUS A. KNUDSON died suddenly at Meadville, Penn., on August 13, 1909. Mr. Knudson was born in Southport, Conn., December 15, 1845, of Norwegian parents. He is survived by a widow. Mr. Knudson had been connected with the Western Union Telegraph Company and with stock-ticker companies in New York. For many years he has been devoting himself to the study of electrolysis by stray railway currents, being one of the pioneer investigators in that field. At the time of his death he was engaged in making an expert investigation of the water mains at Meadville. Mr. Knudson was a member of the American Institute of Electrical Engineers.

Mr. Knudson was elected a member of the New England Water Works Association, September 11, 1902.

GEORGE H. BISHOP died at Watch Hill on August 19. Mr. Bishop was born in Middletown, Conn., June 7, 1831. He was the son of Giles Bishop. Mr. Bishop entered the engineering profession at an early age, becoming associated with George Norman, a well-known hydraulic engineer. Since that time Mr. Bishop has designed many water systems and frequently acted as expert in the construction of water works, and has been called many times as an expert witness to give testimony concerning water rights and construction. About 1870 Mr. Bishop married Miss Purple, of Illinois. While never holding public office, Mr. Bishop took a prominent part in the affairs of the Knights of Pythias as well as other fraternal orders.

Mr. Bishop was elected a member of the New England Water Works Association on June 16, 1886.

BOOK REVIEWS.

IRRIGATION ENGINEERING. By Herbert M. Wilson, C. E. Sixth edition, revised and enlarged. 8vo. xxix+625 pages, 38 full page plates, and 195 figures. New York: John Wiley & Sons. 1909. Cloth, $4.00.

The first edition of this book was published in 1893. The present edition, the sixth, has been entirely rewritten, as the author states in the preface, to bring to date the great progress made in construction work and to show the important changes in design brought about by the general adoption of reinforced concrete for the structures needed in irrigation projects.

The work is, in the main, a presentation of the current Western practice in irrigation, although it contains descriptions of many foreign works. It is, therefore, of value to the practicing engineer as giving numerous illustrations of existing works. Its principal value to Eastern engineers and water-works men is its description of the methods used in constructing the earth dams, with the piping and gate chambers, and typical specifications and the tables of the unit costs prevailing on the government work. The discussion of pumping machinery with the relative costs of the different types of plants is also interesting, though there are not enough figures as to the cost of coal and other materials and the rate of wages to make these figures comparable with those derived from Eastern practice.

The government has such elaborate methods of cost keeping in the Reclamation Service that it seems a pity that more unit costs could not be given.

The book is also of considerable value as a text-book for students' use, and particularly valuable in connection with a course in hydraulics. In such a case the chapters on the flow of water in pipes and channels, and the theory of the design of dams, could be omitted, leaving the interesting reading matter on the practical application of hydraulic problems in innumerable cases.

The book is divided into three parts: Hydrography; Canals and Canal Works; and Storage Reservoirs.

Under the first part, the author discusses:

Rainfall, run-off, stream flow, evaporation, absorption, seepage, the measurement of water flow in open channels, the quantity of water required, and the use of sewage for irrigation purposes.

In this discussion, which comprises about one fifth of the book, the author presents tables of statistics, diagrams and illustrations, and numerous lists of references for the subjects treated.

Under "Canals and Canal Works," the author presents definitions of the different types of canals; methods of aligning the slopes and cross-sections employed; headworks, diversion weirs, sluiceways, regulators, falls, distributaries; and discusses the flow of water in pipes and the methods of applying the water to the fields.

In the discussion, which comprises about one half of the book, the author goes into considerable detail, giving numerous illustrations of actual structures as well as many references.

Under "Storage Reservoirs," the author discusses their location and capacity, the construction of dams; wasteways and sluices; and pumping tools and maintenance, concluding with a short description of the United States Reclamation Service.

This part takes up about one quarter of the book and is probably the most interesting to Eastern engineers as it presents a study of reservoirs and dams, with a description of some of the big dams in the country and the cost of the storage provided. The discussion of the various methods of pumping, with the efficiency and approximate cost of each method is also exceedingly interesting.

SANITATION, WATER SUPPLY AND SEWAGE DISPOSAL OF COUNTRY HOUSES. By William Paul Gerhard, C.E. 12mo. xx+346 pages, 113 full page plates and figures. New York: The D. Van Nostrand Company. 1909. Cloth, $2.00.

The author states in the preface that it has been his aim throughout the work to inform the reader "What to do" rather than "How to do it," and that he has omitted many details regarding the execution of sanitary methods, avoiding in this way the encouragement of "amateur sanitary engineering."

There is little doubt that this lack of detail results in great loss in the value of the book, particularly to the engineer and architect. With the exception of this lack of detail, the book gives a very good summary of the various subjects treated and suggests many ideas for the design of small plants. The book is well arranged and the illustrations are, for the most part, well chosen. There is, however, no index.

This book, as suggested by the title, is divided into three parts, Sanitation, Water Supply, and Sewage Disposal of county houses, institutions, and hotels located out of reach of the water and sewerage systems of the community.

In the first part of the book, Sanitation, the author discusses the desirability of sanitary surroundings, and shows the necessity of good location, ventilation, surface drainage, and the proper methods of lighting and heating. This part concerns the householder and builder much more than it does the architect or engineer.

In the second part, Water Supply, the author describes the different sources of supply and methods of pumping, distribution, and storage, followed by a description of actual plants. It seems strange that water filters are not given more consideration in this connection. It is frequently possible with very simple filters or aërating devices to purify water that could not otherwise be used with comfort. It seems to be the opinion of the best hydraulic engineers that purity of surface waters, however careful the inspection of the watershed may be, cannot be depended upon, and that the time is not far distant when state laws will compel the filtration of all public surface water supplies. It would seem, therefore, particularly in the case of institutions or sanatoria, that a consideration of this problem would be of the utmost importance.

In the third part, Sewage Disposal, the author discusses cespools, subsurface irrigation, septic tanks, contact beds, and filters. There is a good description of the different processes from an elementary point of view, followed by some plans of the various types of purification plants as actually put in.

As mentioned before, the greatest fault in the book from the point of view of engineers is the omission of the definite information so necessary for the design of such plants, as well as the relative economy of the various types. The cost of these small installations for country estates is generally in excess of those for towns in proportion to the size, and is rather difficult to estimate, so that if the author had given the cost of the various works he described he would have added greatly to the value of the book. Nevertheless, the book presents many valuable ideas in the design of such plants and should be extremely useful to architects and engineers who install them.

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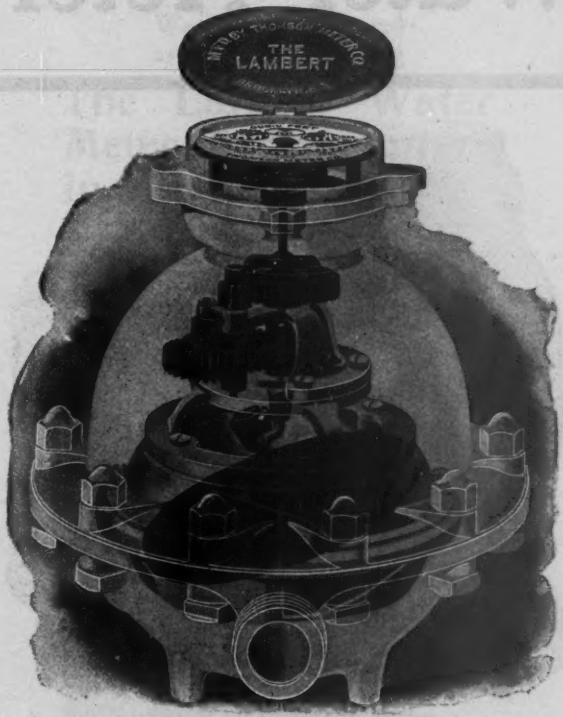

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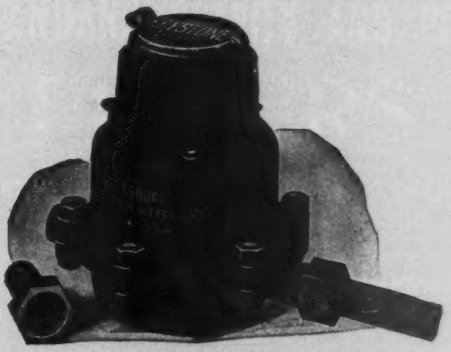

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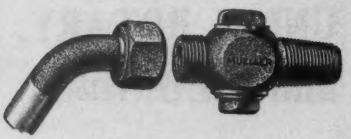

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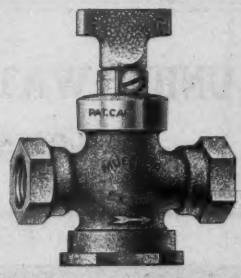

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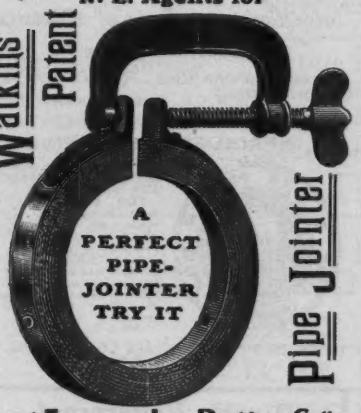

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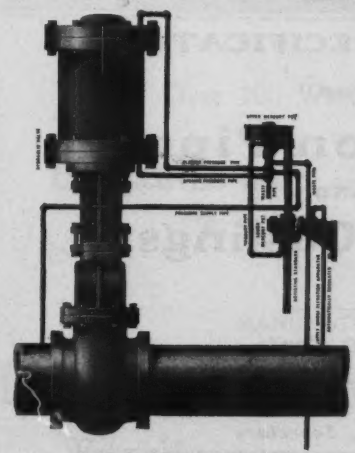

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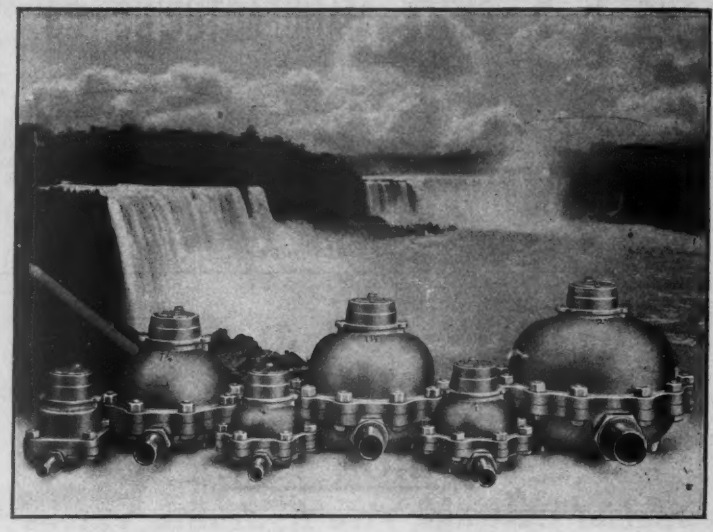

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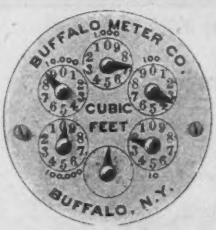

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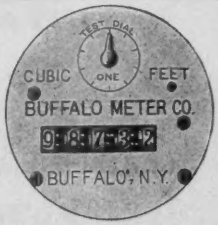

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ESTABLISHED 1892

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FILTERS
REGULATORS
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We make **Pressure Regulating Valves** for all purposes, steam or water.

Our **Feed-Water Filter** will keep oil out of your boiler.

We can interest you if you use a condenser.

Water Engines for Pumping Organs

THE ROSS VALVE MFG. CO.

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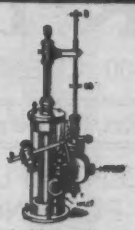

Standard for pumping church or parlor organs. Ask your organ builder for it or write us.

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NOTICE—WE HAVE ARRANGED TO MANUFACTURE THE CELEBRATED

WALKER FIRE HYDRANT

ONE OF THE BEST HYDRANTS MADE

MECHANICAL FILTRATION

PLANS AND ESTIMATES CHEERFULLY SUBMITTED

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FOR WATER AND GAS

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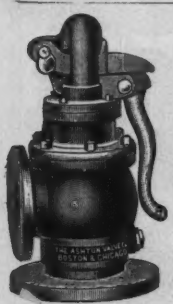

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Superior in Quality of material and workmanship, and with greatest efficiency and durability, they challenge comparison with any others on the market. Send a trial order subject to approval ONLY IF SATISFACTORY, and thereby prove the claims made for them. HIGH GRADE GOODS OUR EXCLUSIVE SPECIALTY.

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Engineers, Iron Founders and Machinists

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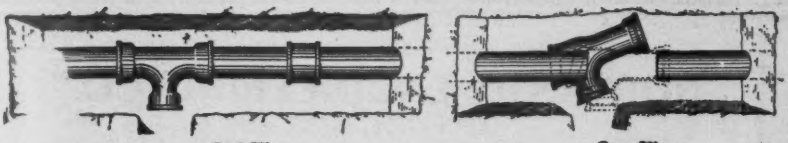
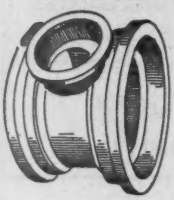
PUMPING ENGINES

Cast Iron Pipe

CUTTING-IN TEES



Old Way *Our Way*



Connections economically and easily made with one fitting. Saves sleeve, cuts, lead and unnecessary work and material.

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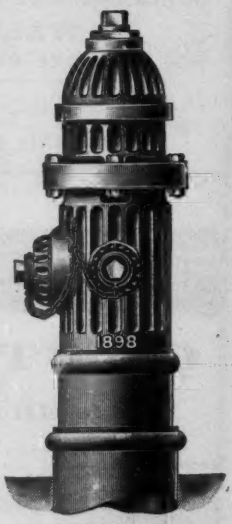
Cost of fittings reduced from 25% to 50%. Full strength. Deep bells. Convenient to handle. Sold by the piece.



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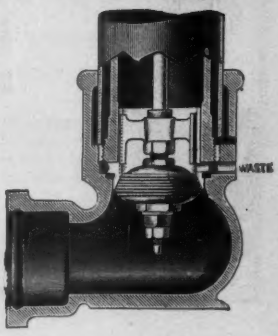
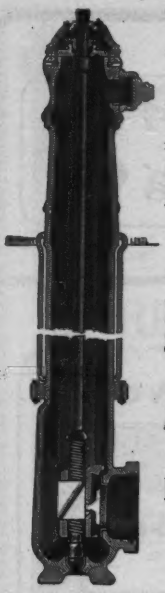
A half century of use has established their reputation as being the most economical, durable and simple hydrant.

Number in use exceeds total of all other makes combined.



Gate Valves

R. D. WOOD & CO. STANDARD
DOUBLE DISK
ANTI-FRICTION
EXTRA WEIGHT, FINISH
AND MATERIAL



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...MANUFACTURERS OF...

VALVES AND FIRE HYDRANTS

This hydrant is anti-freezing, because when the drainage is good no water is left in it to freeze.
The drip is directly in the bottom of the hydrant and drains perfectly. It is protected by its valve, which never leaves its socket and cannot be clogged.

DOUBLE AND SINGLE GATE VALVES,
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FOOT VALVES.

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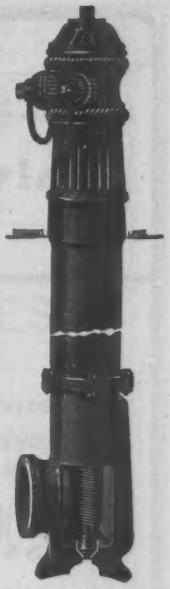
☞ SEND FOR CIRCULARS. ☜



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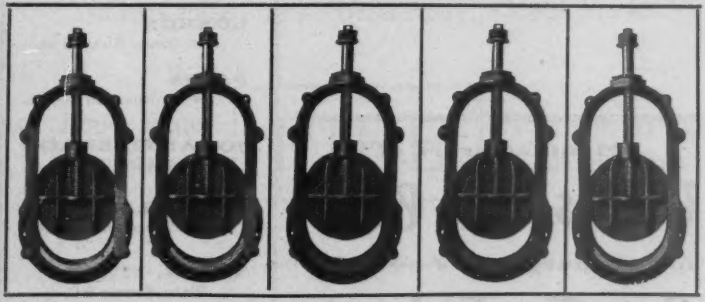
Coffin Valve Company,

Boston, Mass.

Makers of the largest Sluice and Gate Valves in America



SLUICE VALVES

of every size and for every condition

GATE VALVES CHECK VALVES FIRE HYDRANTS

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Manufacturers of

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for all purposes Also

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SIMPLE
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ALL SIZES ALL PRESSURES

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Cast Iron Water and Gas **PIPE** From 3 to 60 inches in diameter.

ALSO

ALL SIZES OF FLANGED PIPE

AND SPECIAL CASTINGS.

Solvay Protective Paints

FOR

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CRYSOLITE

PROTECTS CORRUGATED IRON and STRUCTURAL STEEL

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PROTECTS STEEL WATER PIPE and SUBMERGED STEEL

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FROM CORROSION

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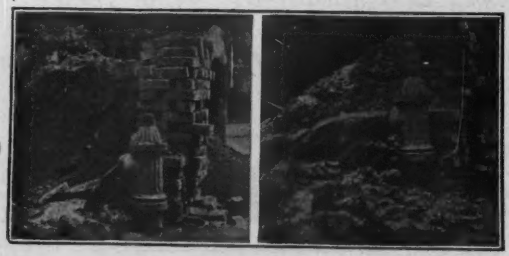
Are You Getting Full Efficiency of Your Water Mains?

Before Cleaning



After Cleaning

July 13, 1907

Fire plug showing increased flow under same pressure at Wheeling, W. Va. :: For further particulars address

National Water Main Cleaning Co., 27 WILLIAM STREET NEW YORK

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MANUFACTURERS OF

FOR WATER AND GAS WORKS

(NEW ENGLAND W. W. ASSOC. STANDARD SPECIFICATIONS)

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EASTERN OFFICE, 220 BROADWAY, NEW YORK

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Also Flange Pipe, Lamp Posts, Street Castings,
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FOR WATER, GAS, SEWERS, DRAINS, ETC.

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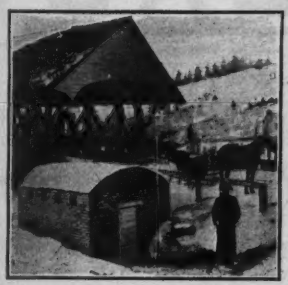
DETECTION OF WASTE WATER

TWO CITIES WHICH SAVED MONEY BY HAVING VENTURI METERS

In the Reservoir Gate House of a certain city was placed in 1900 the Register of a 30-inch Venturi Meter. Its readings showed great waste of water and led to the general adoption of house meters. The daily per capita consumption was then 84 gallons; in 1907 it was 59 gallons. At present only 16% of the Venturi's readings is not accounted for by the small meters.

One day the Water Department gave the street mains a thorough flushing out by opening the fire plugs and some underground blow-off connections to the sewers. After this flushing, the Venturi Meter showed an increased discharge of about 1,500,000 gallons per day, and as this continued for about two weeks it was thought that the increased reading was caused by some derangement of the meter, due to the abnormal flow of the flushing. Nevertheless, *because of the meter readings*, a five days' diligent search for leaks was made and one of the underground blow-off valves was found *open*. As soon as this was closed the meter readings fell off to the previous normal consumption.

It is altogether probable that water would have poured through this valve indefinitely, had it not been for the Venturi Meter.



The Register of the 10-inch Meter at another city is kept in the house shown in our illustration. The temperature is frequently 30° below zero, but the readings are not affected. At one time this meter registered abnormally large quantities of water. A diligent investigation of several days showed that a break in the distributing pipe was carrying large quantities of water directly into the sewer. To those in charge of the Water Company there was absolutely no indication of this leak except that given by the Venturi meter.

Cities with Venturi Meters soon discover such waste of water. It is more than possible that similar losses are taking place in other cities where there are no Venturi Meters to give warning.

BUILDERS IRON FOUNDRY

PROVIDENCE, R. I.

Chadwick-Boston Lead Co.

Corner Congress and Franklin Streets

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LEAD PIPE AND SHEET LEAD

Patent Tin-lined Pipe

Pure Block Tin Pipe

PIG LEAD

(Best Brands for Joint Work always in Stock)

Pig Tin, Wire Solder, Pumps, etc.

ALSO

"Forest River" and "Star" Brands

PURE WHITE LEAD

AGENTS FOR

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This packing is adapted to the highest pressures and superheated steam; it can be used on pressures up to 300 lbs. and temperatures of 800° to 1000° Fahrenheit. It is naturally well adapted for low pressures and low temperatures. Regularly furnished in sheets 4½ x 4½ feet, or can be supplied if desired in sheets 4½ x 9 feet.

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for small valve stems (in spool form). Sizes ⅛, 3/16, ¼; also braided, round and square, sizes ¼ to 2 inch. Always soft and pliable.

"SKOOKUM" PACKING

Cross expansion piston packing, used with steam up to 150 lbs. pressure, with hot orcold water.

DANIELS P. P. P. PACKING

(Regular and Special)

The packing made of two wedges and a yielding absorbent cushion. In places where packings have worn out in a few weeks, P. P. P. has lasted months.

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